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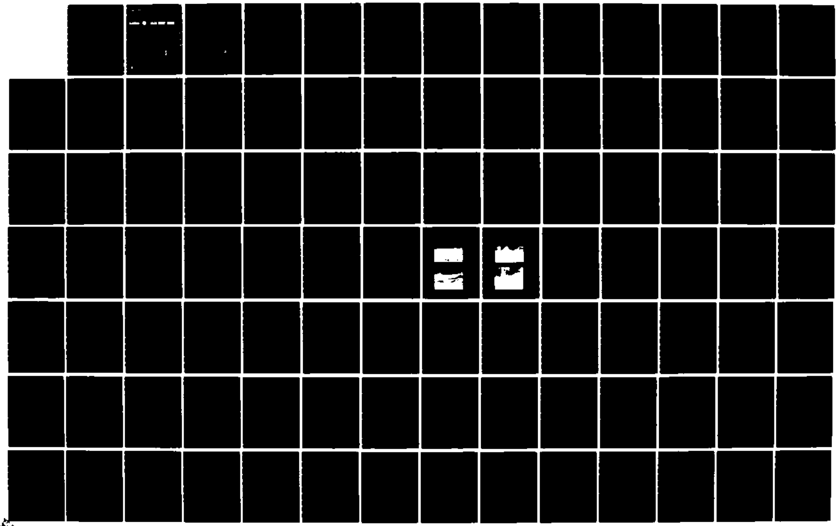

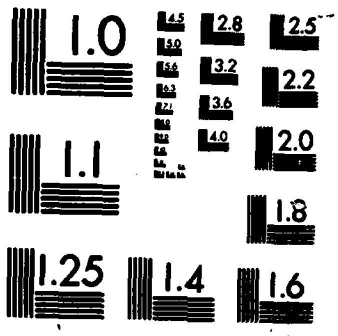

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ALABAMA SOLAR ENERGY CENTER

BIOMASS FEASIBILITY STUDY FOR MILAN, INDIANA AND KANSAS ARMY AMMUNITION PLANTS

April 1983

Prepared For:

U.S. Army Corps of Engineers
Huntsville Division

Contract No. DACA87-82-C-0075

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Prepared By:

The University of Alabama, Huntsville

With Contributions By:

Georgia Institute of Technology

The Alabama Solar Energy Center is operated
by The University of Alabama in Huntsville
Kenneth E. Johnson Environmental and Energy Center
Huntsville, Alabama 35899 - (205)895-6361

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Written by:

M. Carl Ziemke

M. Carl Ziemke, P.E.

Joseph F. Peters

Joseph F. Peters

Approved by:

Gerald R. Guinn

Gerald R. Guinn, Ph.D.
Principal Investigator

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER HNDTR-83-66-ED-PM	2. GOVT ACCESSION NO. AD-A150 814	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) BIOMASS FEASIBILITY STUDY FOR MILAN, INDIANA AND KANSAS ARMY AMMUNITION PLANTS		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER UAH REPORT NO. 357
7. AUTHOR(s) GERALD R. GUINN, JOSEPH F. PETERS, M. CARL ZIEMKE		8. CONTRACT OR GRANT NUMBER(s) DACA87-82-C-0075
9. PERFORMING ORGANIZATION NAME AND ADDRESS THE UNIVERSITY OF ALABAMA IN HUNTSVILLE HUNTSVILLE, AL 35899		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US ARMY CORPS OF ENGR, HUNTSVILLE DIV P.O. BOX 1600, WEST STATION HUNTSVILLE, AL 35807-4301		12. REPORT DATE APRIL, 1983 13. NUMBER OF PAGES 123 PGS
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

DISTRIBUTION STATEMENT A: APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SOLID FUELS	BOILERS	MUNITIONS INDUSTRY
WOOD	LIFE CYCLE COSTS	SAWDUST
WASTES(INDUSTRIAL)	RESIDUES	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

THE FEASIBILITY STUDY DESCRIBED IN THIS REPORT WAS PERFORMED FOR THE HUNTSVILLE DIVISION, U.S. ARMY CORPS OF ENGINEERS, BY THE UNIVERSITY OF ALABAMA IN HUNTSVILLE, ASSISTED BY THE GEORGIA INSTITUTE OF TECHNOLOGY. THE PURPOSE OF THE STUDY WAS TO DETERMINE THE ADEQUACY AND COST OF SOLID BIOMASS FUEL AS A POTENTIAL REPLACEMENT FOR COAL AS BOILER FUEL AT THREE ARMY AMMUNITION PLANTS (AAPs). THE STUDY IS ORGANIZED TO PROVIDE THE BASIC INFORMATION PERTINENT TO EACH OF THE THREE AAP's WITHIN THE FIRST FOUR CHAPTERS.

THE REST OF THE REPORT IS CONFIGURED TO CONTAIN DETAILED CALCULATIONS AND BASIC TECHNICAL DATA ABOUT THE MAJOR SOURCES OF SOLID BIOMASS FUEL CONSIDERED AS CANDIDATES TO REPLACE COAL.

DISCLAIMER

The views, conclusions, and recommendations in this report are those of the authors, who are solely responsible for the accuracy and completeness of all information. The contents of this report do not reflect necessarily the official views and policies, expressed or implied, of the University of Alabama in Huntsville, the Kenneth E. Johnson Environmental and Energy Center, the Alabama Solar Energy Center, the U. S. Army Corps of Engineers, Huntsville Division or the Georgia Institute of Technology.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to those who contributed to the study efforts and to the preparation of this report.

Special mention should be given to the contributions made by Mr. William Bulpitt and Mr. David Harris, of the Georgia Institute of Technology, who participated in all of the site surveys and provided significant portions of the report.

Special mention is also due Mr. A.B. Curtis, USDA Forest Service, who provided significant insight into woody biomass as an energy resource.

Leadership and assistance given to the study and preparation of this report by Mr. Morgan Jones, P.E., of the U.S. Army was exceptionally valuable in adding to the quality of the results.

Finally, special thanks are due Mrs. Beverly Sandlin who patiently and skillfully prepared the draft and final versions of this report.

FOREWORD

The feasibility study described in this report was performed for the Huntsville Division, U.S. Army Corps of Engineers, by the University of Alabama in Huntsville, assisted by the Georgia Institute of Technology. The purpose of the study was to determine the adequacy and cost of solid biomass fuel as a potential replacement for coal as boiler fuel at three Army Ammunition Plants (AAPs). The study is organized to provide the basic information pertinent to each of the three AAP's within the first four chapters. The rest of the report is configured to contain detailed calculations and basic technical data about the major sources of solid biomass fuel considered as candidates to replace coal.

ABSTRACT

The purpose of this study was to determine the feasibility of using solid biomass fuel instead of coal as boiler fuel at the Army Ammunition Plants (AAPs) at Parsons, Kansas, Milan, Tennessee, and Charlestown, Indiana. The University of Alabama in Huntsville and the Georgia Institute of Technology reviewed earlier contractor studies of the steam power situation at each AAP before visiting each plant site. During the site visits, the recommendations of the contractor studies relative to biomass fueling of a central boiler facility were reviewed with appropriate AAP personnel by the feasibility study team. Also reviewed were site land management plans including those for on-site forests.

During each site visit, state foresters were contacted for help in assessing the adequacy of solid biomass fuel sources within 50 miles of each AAP. In each case, this information was supplemented by a team field survey of biomass fuel supplies. The solid biomass fuels considered were chips obtained from processing whole trees and forest residue, chips from special short rotation forests (fuelwood plantations), wood waste from mills, agricultural residue and processed biomass fuel pellets. Fuelwood plantations were only considered as on-site fuel options but wood chips from mature forests, both on-site and off-site, were investigated.

The study showed that only Milan AAP had a mature forest large enough to supply the Minimum Sustaining Rate (MSR) central boiler fuel but the delivered cost was greater than that of available coal. Only mill waste fuel (sawdust and bark) has a lower delivered price than coal at the three AAPs. At Milan AAP and Indiana AAP, adequate supplies of mill waste fuel are available to satisfy MSR central boiler fuel needs. No type of biomass fuel is practical at any of the AAPs for meeting central boiler fuel requirements for mobilization. Coal must be used as the primary fuel for this condition.

Life cycle cost analyses of the entire central boiler plants at Milan AAP and Indiana AAP are necessary to determine if the use of sawdust and bark fuels is truly competitive with bituminous coal. Thus no biomass fuel can be recommended as a primary boiler fuel at any of the three AAP's at this time.

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LIST OF ABBREVIATIONS, ACRONYMS, AND BREVITY CODES

The following abbreviations and acronyms are used in the text of this document.

AAP	Army Ammunition Plant
BTU	British Thermal Unit
D&Z	Day and Zimmerman
Ft	Feet
Ft^3	Cubic feet
G/C	Gilbert/Commonwealth
ha	Hectare
hr	Hour
IAAP	Indiana Army Ammunition Plant
KAAP	Kansas Army Ammunition Plant
kWhr	Kilowatt hour
LAP	Load, Assemble and Pack
lb	Pound
lb/ft^3	Pounds per cubic foot
MAAP	Milan Army Ammunition Plant
MBTU	Millions of British Thermal Units
N/A	Not applicable
mbf	Thousands of board feet
mmbf	Millions of baord feet
MSR	Minimum Sustaining Rate
ODMT	Oven dried metric tons
P&E	Propellant and Explosive
UAH	University of Alabama in Huntsville
USDA	United States Dept. of Agriculture
S&T	Sanders and Thomas
yr	Year

BIOMASS FEASIBILITY STUDY
FINAL REPORT

CHAPTER 1

INTRODUCTION

1-1 BACKGROUND

Military installations are potentially attractive opportunities for the utilization of solid biomass fuel as a low cost domestic source of energy for process and space heating. Central energy plants are often used, thus facilitating the transportation, handling, storage, preparation and combustion of any solid fuel. For security reasons, military bases are usually located on vast acreages of land which are capable of, or are already supporting significant stands of timber. Because these areas are public lands, management of fuelwood plantations, production methods and impacts on the environment can be monitored, evaluated and controlled. In addition these military installations are often located in rural areas where lumber operations can provide residue from timber harvesting and wood products manufacturing. Before solid biomass is seriously considered as an energy source however, four important considerations must be addressed. They are: 1) abundance of the raw material supply 2) availability 3) environmentally sound harvesting practices and 4) cost competitiveness with traditional fossil fuels.

The effort described in this report was undertaken for the Huntsville Division, U.S. Army Corps of Engineers, to determine the feasibility of using local biomass fuel sources for satisfying the major energy requirements for Army Ammunition Plants (AAPs) at Parsons, Kansas, Milan, Tennessee and Charlestown, Indiana. The prime contractor for this study was the Johnson Environmental and Energy Center of the University of Alabama in Huntsville (UAH), supported by the Georgia Institute of Technology Engineering Experiment Station. This work was accomplished between 13 September, 1982 and 30 April, 1983 and used, as a point of departure, three previously conducted EEAP and biomass energy studies. Other contractors had already determined the energy requirements for both peacetime and mobilization operations at all three sites and had made preliminary evaluations of the biomass fuel supplies at each site. The objective of the present effort was to further extend these evaluations by the development of a more detailed data base which could lead to conclusive feasibility recommendations.

1-2 SCOPE OF WORK

The study was limited to the technical and economic considerations of a biomass fuel supply delivered to a storage area at the boiler plant. Outside the scope of the study were considerations of fuel related conversions, such as boiler modifications, and equipment, used for biomass fuel preparation, unloading, storage and delivery. Biomass fuel influences the boiler performance because of the generally high moisture content. Because alternative fuels must be compared on the basis of energy delivered to the load, boiler efficiency was considered to account for these effects. The previously conducted EEAP studies were used as a source of cost information on coal which was used as a measure of feasibility for solid biomass fuel.

1-3 METHODOLOGY

The study addressed economic, technical and societal considerations of utilizing solid biomass fuel as an alternative to coal at the following AAPs:

- Kansas
- Milan (Tennessee)
- Indiana

Specifically, the following methodology was used for each site:

Site Assessment - Each of the sites was visited by a site assessment team. A definition of the steam requirements was conducted through review of the previously conducted studies and data supplied by the Facility Engineer. Also considered was the identification of the location, size, condition and age of boilers which are potentially convertable to wood firing or which might be replaced in the near future and thus be prime candidates for wood firing.

Resource Assessment - Forest products manufacturing industries and harvesting operations proximate to the AAP (50 mi) were canvassed and data were collected on wood use and disposition of wood residue. The potential biomass fuel sources considered were:

- Forest residue (slash)
- Fuelwood obtained by whole tree chipping
- Fuelwood from energy forests (fuelwood plantations)
- Residue from wood processing (sawmills, etc.)
- Agricultural residue (straw, stover, etc.)
- Processed biomass fuel pellets

The assessments were conducted by a team from UAH and Georgia Tech and consisted of site visits, mail surveys and material supplied by state foresters. Efforts were also made to identify and contact wood brokers in the market range of each AAP. Surveys of wood availability were made on each AAP site and were conducted by the team with the aid of the facility engineer and staff.

Resource Development - Efforts were made to identify the potential for additional production of biomass on Government owned lands. Specific land management issues considered included:

- Reforestation, selective harvesting and other silviculture techniques which permit full utilization of the inherent production capacity of the land for meeting the AAP's peacetime and mobilization energy requirements

- Intensive management approaches which increase the production capacity of the land (energy forests).

The potential for resource development was made with the aid of the State Forestry Service and the land management specialist of each AAP.

Resource Acquisition - Strategies were considered to provide biomass fuel to the boiler site. Specific cost and supply issues included:

- Contractor operator costs to harvest timber stands within the plant confines.

- Purchase of manufactured biomass fuel pellets and wood residues from area mills, logging operations and wood products manufacturers.

- Purchase of baled agricultural residue from nearby farms.

- Harvesting technologies suitable for the existing, or anticipated, timber stands on the base. Capital costs, operating and maintenance costs were also identified.

- Transportation and unloading systems to move the biomass fuel from the growing area to the boiler site. Hauling costs of area suppliers were determined and additional facility requirements at the central plant site were defined and costs estimated.

Mill operators, forest owners, logging contractors and fuel brokers were contacted to identify acquisition strategies that provide

assured supply at reasonable costs. The acquisition data included considerations such as:

- long term availability
- procurement methods
- quality available
- heating value
- seasonal fluctuations
- risk of supply interruption
- current and future costs

Cost Estimates - An analysis of the viability of a fuel delivery system included economic factors as well as technical factors. Capital, operating and maintenance costs of production and delivery to stock piles were generated and developed and formatted to facilitate subsequent analyses by the Government. The various cost items outlined below were provided:

Capital Costs

- harvesting equipment
- transportation equipment
- unloading facilities
- preparation facilities
- storage equipment and facilities

Labor Costs

Purchased Fuel Costs

- purchased biomass
- liquid fuel
- electric power

Maintenance Costs

Replacement Costs

Profit

Using the basic cost data outlined above, normalized cost in dollars per ton and dollars per million Btu of delivered steam were derived.

Application Evaluation - A comparative evaluation of biomass fuel as an alternative to coal was conducted. Technical and economic parameters for coal were obtained from previous studies of the three AAP's. Similar data on biomass were developed from the activities described in the preceeding paragraphs. Evaluation factors include:

- o Capital and O&M costs
- o Availability
- o Reliability of supply
- o Unit costs

1-4 EMPHASIS OF STUDY

In this study, a detailed methodology was chosen to evaluate six different potential sources of biomass fuel (see previous section). However, it was determined early in the study that wood processing residue and wood chips derived from either whole trees or forest residue were the only biomass fuel sources likely to compete with low cost ($42/ton - $49/ton) coal available at the AAPs. Therefore, to better utilize time and manpower resources, the emphasis of this study was directed at obtaining detailed information on these biomass fuel sources. Nevertheless, the study did produce sufficient information on all potential sources of solid biomass boiler fuel to permit evaluation of their relative abundance and cost.

Another early shift in study emphasis occured relative to the estimation of the cost of handling wood fuel between the primary point of supply (truck dump) and the fuel pile. This materials handling equipment is referred to herein as "boiler-site" equipment. The total costs of operating this equipment were estimated in order to provide an insight to the additional costs of handling biomass fuel at the boiler site when a boiler is selected to burn both biomass fuel and coal. The coal handling equipment would have to be purchased in all cases both to provide dual-fuel capability and to permit the rapid increases to the higher boiler output requirements that would occur during mobilization operations.

The costs of the required boiler-site biomass fuel handling equipment and the fuel harvesting and transportation costs were estimated on a private contractor basis which is probably not realistic for the operation and ownership of fixed equipment on a Government reservation. Nevertheless, the equipment descriptions and related costs developed provide useful data for further in-depth economic evaluations of the total cost of the biomass fueling option at a boiler site. The basic thrust of this study has been to present biomass fuel costs on the same basis as those of the coal available at the AAPs. That is, all cost comparisons are based on the fuel price as delivered on-site in the railcar or truck.

Early study efforts showed that there was little that could be recommended in the area of on-site silviculture to improve the yield of standing AAP forests or to advance the art of short rotation forestry (energy plantations). Each of the three AAPs has a long-standing land management plan, competently administrated and

coordinated with appropriate Federal authorities to ensure good conservation practices and conformity with environmental regulations. Also, the state-of-the-art of fuelwood plantations is such that further study of this technique by the UAH team appears unwarranted. Consequently, this study has de-emphasized pursuit of improved land management (resource development) as a practical means of ensuring adequate supplies of low-cost fuelwood from the AAP sites.

1-5 ORGANIZATION OF REPORT

This report is organized to serve two primary purposes. First, the results of the site assessment, and the assessment of biomass fuel sources, development, acquisition, cost estimates and comparison to coal costs at each AAP are presented on a stand-alone basis. To facilitate rapid review of the individual chapters covering the analysis of each AAP much of the background information, including tables, figures and calculations, has been placed in Chapters 5 through 11.

Secondly, the background section of this report (Chapters 5-11 plus Appendices) has been written so as to provide a data base or reference handbook for future biomass fuel feasibility studies. It has been determined that costs of the most economical biomass fuel (sawdust and bark) have remained relatively constant over the past decade and seem likely to continue so into the near future. Also, wood fuel brokerage fees have historically remained relatively constant at about $2.00/ton. Therefore, the costs calculated for fuel based on sawdust and bark supplies should be valid for some time into the future, enhancing the reference value of this report.

The introduction to this report (Chapter 1) serves as an executive summary, and as such contains all of the basic results and conclusions of this study.

1-6 RESULTS

The detailed results of the site visits and subsequent analyses by the UAH team are given in Chapters 2, 3 and 4 for the Kansas, Milan and Indiana AAPs, respectively. In the subsequent sections, only a brief condensation of the site analyses are provided.

a. Kansas Army Ammunition Plant (KAAP). The review of the Day and Zimmerman (D&Z) Report (Reference 1) in the areas of recommended central boiler plant and biomass fuel alternatives provided some data with which to compare the results of the UAH teams's site visit and subsequent analysis. These data are given in Table 1-1.

TABLE 1-1

COMPARISON OF UAH KAAP DATA WITH D&Z DATA

	D&Z	UAH
MSR Coal Requirements	12,000 tons/year	12,000 tons/year
MSR Wood Fuel Requirements	51,700 tons/year	36,000 tons/year
Mill Residue Availability	20,000 tons/year	24,000 tons/year
Coal Costs	$42/ton	$42/ton

There was little else to compare between the contractor (D&Z) studies and UAH findings in the area of biomass fuels because D&Z did not attempt to locate any other sources of biomass boiler fuel or to establish relative costs.

The results of the KAAP site visit and subsequent calculations are shown in Table 2-3. The low cost of coal delivered to KAAP ($42/ton) makes all types of biomass fuel too expensive to use except for sawdust and bark, which are not available in sufficient quantity.

TABLE 2-3

SUMMARY OF FUEL OPTIONS AT KAAP*

Description of Option	Adequacy	Cost ($/MBTU/STEAM)
Bituminous Coal	Adequate	2.19
Sawdust and Bark	Inadequate	1.84
Forest Residue (Slash)	Marginal	2.78
Agricultural Residue	Adequate	3.23
Existing AAP Forest	Inadequate	**
Off-Site Whole Tree Chips	Adequate	2.78
AAP Fuelwood Plantation	Adequate	4.58
Wood Fuel Pellets	Inadequate	3.91

*Does not reflect differential boiler costs
**Quantity is too small for efficient harvesting

b. Milan Army Ammunition Plant (MAAP). The contractor previously analyzing steam power facilities at MAAP was Gilbert/Commonwealth (G/C) so the UAH team reviewed the G/C report (Reference 6) for data in the areas of recommended central boiler

plant and biomass fuel alternatives. The G/C data are compared with data developed by UAH in Table 1-2.

TABLE 1-2

COMPARISON OF UAH MAAP DATA WITH G/C DATA

	G/C	UAH
MSR Coal Requirements	9,860 tons/year	9,860 tons/year
MSR Wood Fuel Requirements	42,225 tons/year	29,580 tons/year
Mill Residue Availability	"Adequate"	42,000 tons/year
Mill Residue Cost	$12.50/ton	$11.30/ton
Coal Costs	$44.67/ton	$44.67/ton

As was the case with D&Z, G/C did not further pursue the biomass option except to state that use of wood as a substitute fuel for coal was not recommended even when the cost of wood was competitive.

Milan Army Ammunition Plant has two sources of on-site fuelwood potentially capable of satisfying MSR fuelwood requirements: (a) an existing 7,000 acre forest and (b) unforested land available for a fuelwood plantation (energy forest). The UAH team conferred with J.R. Covington of the MAAP staff regarding the existing management plan for the standing timber. From this discussion, it does not appear feasible to use this timber for fuelwood (Section 3-2 d.). Nevertheless, costs of harvesting and transporting whole tree chips from this forest was calculated and was determined to total $17.24/ton.

A fuelwood plantation on MAAP land would utilize all of the 5,335 available acres, and would produce the MSR requirement of 29,580 tons/year five years after first planting (Section 3-2 d.). However, at $34.48/ton this option is almost twice as expensive as the use of standing timber.

The forest residue (slash) from the existing MAAP forest would not be adequate for MSR fuelwood needs. However, there is adequate slash off-site from on-going logging operations. A TVA survey (Table 7-2) was used to predict a slash supply of 500,000 tons/year within 50 miles of MAAP. The cost of providing wood chips from this slash to MAAP was estimated to be $18.71/ton (Section 3-2 b.).

Because slash is a byproduct of logging, the weight of whole trees harvested is even greater than that of slash (Table 7-1).

A summary of fuel options at MAAP is given in Table 3-3. Sawdust and bark represent an adequate, cost-effective biomass fuel. All other adequate biomass fuels are too expensive to compete with $44.67/ton coal.

TABLE 3-3

SUMMARY OF FUEL OPTIONS AT MAAP*

Description of Option	Adequacy	Cost ($/MBTU/STEAM)
Bituminous Coal	Adequate	2.33
Sawdust and Bark	Adequate	1.77
Forest Residue (Slash)	Adequate	3.07
Agricultural Residue	Inadequate	N/A
Existing AAP Forest	Adequate	2.69
Off-Site Whole Tree Chips	Adequate	2.92
AAP Fuelwood Plantation	Adequate	4.72
Wood Fuel Pellets	Unavailable	N/A

*Does not reflect differential boiler costs

c. Indiana Army Ammunition Plant (IAAP). The Sanders and Thomas (S&T) contractors study was reviewed prior to the IAAP site visit (Reference 7). This study did not provide acceptable data for the selected central boiler house option. Therefore, during the site visit, the UAH team conferred with IAAP personnel to size the possible new central boiler plant in the Load, Assemble and Pack (LAP) area. It was determined that the oil-fired boilers to be replaced in this area consumed 1,000,000 gallons of fuel oil annually. This is equivalent to a coal requirement of 5,833 tons/year for the new central boiler plant.

The equivalent MSR green wood fuel requirements for the proposed LAP central boiler plant would be (3)(5,833 tons/year) = 17,500 tons/year using a wood/coal ratio of 3:1 (Chapter 10).

A summary of IAAP boiler fuel options is given in Table 4-1. Of the adequate fuel supplies, only sawdust and bark are cost effective. The wood chips produced from adequate off-site whole trees and forest residue are not cost-effective.

TABLE 4-1

SUMMARY OF FUEL OPTIONS AT IAAP*

Description of Option	Adequacy	Cost ($/MBTU/STEAM)
Bituminous Coal	Adequate	2.56
Sawdust and Bark	Adequate	1.55
Forest Residue (Slash)	Adequate	3.07
Agricultural Residue	Marginal	7.41
Existing AAP Forest	Inadequate	**
Off-Site Whole Tree Chips	Adequate	3.07
AAP Fuelwood Plantation	Inadequate	N/A
Wood Fuel Pellets	Unavailable	N/A

*Does not reflect differential boiler costs
**Quantity is too small for efficient harvesting

1-7 CONCLUSIONS AND RECOMMENDATIONS

a. Economics of Sawdust and Bark as Fuel. A comparison of the summaries of the biomass fuel options at the three AAPs (Tables 2-3, 3-3 and 4-1) show that sawdust and bark (when available) are the only cost-effective substitute for low-cost ($42/ton - $49/ton) coal. The energy costs for sawdust and bark at the AAPs ranged from 1.54 - 1.84 $/MBTU Steam whereas the range of energy costs when using coal was 2.19 - 2.56 $/MBTU Steam. It is predicted that this relationship between mill residue costs and coal costs will continue into the near future. It should be emphasized that, while the cost of wood fuel is most favorable at IAAP (39% cheaper than coal), this advantage does not mean, however, that the life cycle cost of operating a wood fuel fired plant is less than that of an equivalent coal-fired boiler plant.

Although total plant life cycle costing was beyond the scope of this study, the following facts must be considered in a final determination of the feasibility of wood fuel.

- All wood-fueled boiler plants must also be able to burn coal either because of need for fuel flexibility and/or to meet larger steam outputs if operation suddenly shifts from MSR to mobilization.

- It is probably not practical to use boiler site fuel handling equipment both for wood and coal (fuel piles and fuel unloading equipment certainly must be separate).

- o Preliminary calculations indicate that the cost of boiler-site fuelwood handling equipment can add \$5/ton - \$11/ton to the cost of green wood fuel.

- o The additional cost of a boiler capable of handling both wood fuel and coal, although not calculated, is known to be considerable.

Because of the previous considerations, it is recommended that a total plant life cycle cost analysis be made to determine the economic feasibility of purchasing boiler equipment capable of burning wood or coal compared to a coal only plant.

The cost of sawdust and bark used herein has included a nominal (\$2.00/ton) wood fuel brokerage fee. In future wood fuel cost analyses, it may be worthwhile to consider the saving of part of this fee by in-house wood purchasing. In areas of plentiful nearby mill waste fuel sources, it may not be necessary to employ a fuel broker.

b. Economics of Wood Chip Fuel. Next to sawdust and bark, wood chips from whole trees or slash appear to be the most economical wood boiler fuel, although they cannot compete with low cost coal. Whole tree chips are especially attractive if they can be obtained on-site, reducing transportation costs. It appears possible that in some cases, wood chip fuel can be cost-effective if the competitive coal is of the high-sulfur type and the use of wood chip fuel can eliminate the significant capital and operating costs of sulfur scrubbing equipment in the boiler stack. Wood fuels contain almost no sulfur and usually contain far less ash than bituminous coal, which could save costs associated with ash removal operations.

c. General Recommendations for Future Studies. The experience gained in this study indicates that biomass fuel pellets, fuelwood plantations and agricultural residue can safely be eliminated from competition with low cost coal as boiler fuel options. Emphasis should be given to mill residue (primarily sawdust and bark) in future wood fuel surveys. The most reliable method of obtaining accurate data on the cost and availability of mill residue fuel is by personal contact. A mail survey was attempted in Kansas with little success.

CHAPTER 2

KANSAS ARMY AMMUNITION PLANT

The purpose of this study is to provide technical and economic data for determination of the feasibility of using biomass as an alternative boiler fuel stock at the Kansas Army Ammunition Plant (KAAP). Biomass supply, costs and application are treated in subsequent sections of this report.

The objective of this section of the study is to determine the long-term availability of solid biomass fuel to satisfy the steam demands at the AAP during peacetime (Minimum Sustaining Rate) operations and mobilization.

2-1 BACKGROUND

The Kansas Army Ammunition Plant (AAP) is located near Parsons in Southeastern Kansas. The KAAP is made up of nine production areas and two support areas, each with their own high pressure boilers. Of these, only Areas 100, 200, 300, and 700 are fully active while 800, 900, and 1100 are partially active. Areas 500, 1000, 1200, and 3000 are inactive. Area 3000 is not included in the study due to its physical remoteness. Except for Areas 200 and 1200, all active boilers are oil fired. Areas 200 and 1200 each have three active coal fired boilers. Area 100 has three inactive coal fired boilers.

A "Study of Steam Generating Facilities at Kansas Army Ammunition Plant" was published in 1981 by Day & Zimmerman (Reference 1). This study identified the annual Minimum Sustaining Rate (peacetime) steam requirements as 222,000,000 lbs. and the annual mobilization steam requirements as 760,700,000 lbs. They further identified the annual coal fuel requirements as 12,000 tons for the Minimum Sustaining Rate and 41,000 tons for mobilization. Day & Zimmerman estimated that the wood chips required to meet the steam requirements are as shown in Table 2-1.

TABLE 2-1

WOOD REQUIRED FOR KANSAS AAP

(Day & Zimmerman Data)

	Tons/Hr	Tons/Yr	$/Ton (1981)	$/Year
MOB	26.54	186,000	35	6,510,000
MSR	12.65	51,700	35	1,810,000

The Kansas State Utilization Forester estimated in February 1981 that the "manufacturing residue" within 50 miles of the KAAP was about 20,000 tons annually (Appendix A).

Based on the above, Day & Zimmerman did not pursue biomass fueling for boilers at Kansas AAP. As is explained in Chapter 10, approximately 3.0 tons of green wood will replace one ton of coal in a boiler. Thus, the MSR wood fuel requirement would be 36,000 tons/year based on 12,000 tons/year coal usage. The UAH team confirmed that $42/ton coal was available delivered to the KAAP.

2-2 BIOMASS SUPPLY SOURCES

The available biomass usable as boiler fuel within economical transportation distance of Kansas AAP (KAAP) was identified as whole tree chipping, forest residue, mill residue, and agricultural residue. Whole tree sources included on-site and off-site woodlands. A survey of these sources was conducted at the site to determine the technical and economic feasibility of using biomass fuel at the KAAP. The results of this survey will be described in detail for each of the biomass sources considered.

Kansas is not usually thought of in connection with commercial forestry. Nonetheless, the net annual harvest of saw timber is approximately 40 million board feet, primarily from forest or woodlands in the Eastern part of the state. Because of the location of the KAAP in Southeastern Kansas, approximately ¼ of the state timber harvest will occur within a 50 mile radius of the plant site. The net annual growth of saw timber on commercial land is approximately 80 million board feet per year (Reference 2). Thus, only about half of the commercial potential is being realized.

Timber production is often given in terms of millions of board feet (mmbf). On the Doyle Scale, sawlogs equal to 1,000 board feet (mbf) weigh 18,000 lbs. Kansas produces 40 mmbf (Doyle Scale) annually which equals 720×10^6 lbs or 360,000 tons delivered to the sawmills.

From Chapter 7, the amount of slash produced from 1,000 bf is (0.8)(18,000 lbs) = 14,4000 lbs. The net harvest of 40 million board feet of saw timber generates altogether approximately

$$(40 \times 10^6) \frac{(14,400)}{(2,000)(1,000)} = 288,000 \text{ tons of forest residue (slash) in}$$

Kansas each year.

Data on the production of potential boiler fuel from sawmill residue, fuelwood plantations, and agricultural residue are given in subsequent sections of this chapter.

a. Whole Tree Chipping. Not all of the timber available in Kansas is within an economical transportation distance from the AAP. However, a 50 mile radius, which is considered an economical transportation distance, covers a considerable area of southwestern Missouri and northeastern Oklahoma. Based on the statistics of Section 2-2, UAH estimates that approximately 90,000 tons/year of sawlogs (¼ of the 360,000 ton state production) are harvested in the Southeastern Kansas area. Figure 2-1 shows the counties within a 50 mile radius of Kansas AAP.

Adequate timber lies within a 50 mile radius of Kansas AAP to meet MSR steam requirements if whole tree chipping is considered for supplying biomass boiler fuel. Based on data from the Kansas Utilization Forester, approximately 80,000 tons/year are harvested in this area. This compares well with the independent UAH estimate of 90,000 tons/year. Because almost ½ this amount would be needed for KAAP boiler fuel, the effect on the local lumber industry could be severe.

As shown in Section 2-2 d., the existing KAAP forest would produce only a very inadequate annual quantity of whole tree chips when compared to MSR wood fuel requirements. Because this quantity is inadequate, whole tree chips must be bought off-site at a delivered cost of $17.90/ton (see Table 5-2). It is calculated that 3.0 tons of green wood are required to replace the energy provided to the steam load by one ton of coal (see Chapter 10). Thus the equivalent wood energy cost is $53.70/ton whereas coal is available delivered to KAAP at $42/ton.

The cost of handling the wood chips at the KAAP boiler site was calculated for reference purposes only. This cost is $5.36/ton (Table 5-3).

b. Forest Residue. In Section 2-2, UAH estimated that the total amount of slash produced in Kansas was 285,000 tons/year (72,000 tons/year is produced in the KAAP area). The area extension forester and the Kansas Utilization Forester estimated in October, 1982 that 40,000 tons/year of logging residue (slash) was available within 50 miles of Kansas AAP. This will marginally satisfy the 36,000 tons of green wood fueling required (See Section 2-1). The cost of harvesting and transporting wood chips derived from off-site slash to KAAP is $17.90/ton (Section 6-1). It will require three tons of wood chips to replace one ton of coal, so the equivalent energy cost of the wood chips is (3)($17.90/ton) = $53.70/ton (Section 6-1). However coal is available delivered to KAAP at $42/ton.

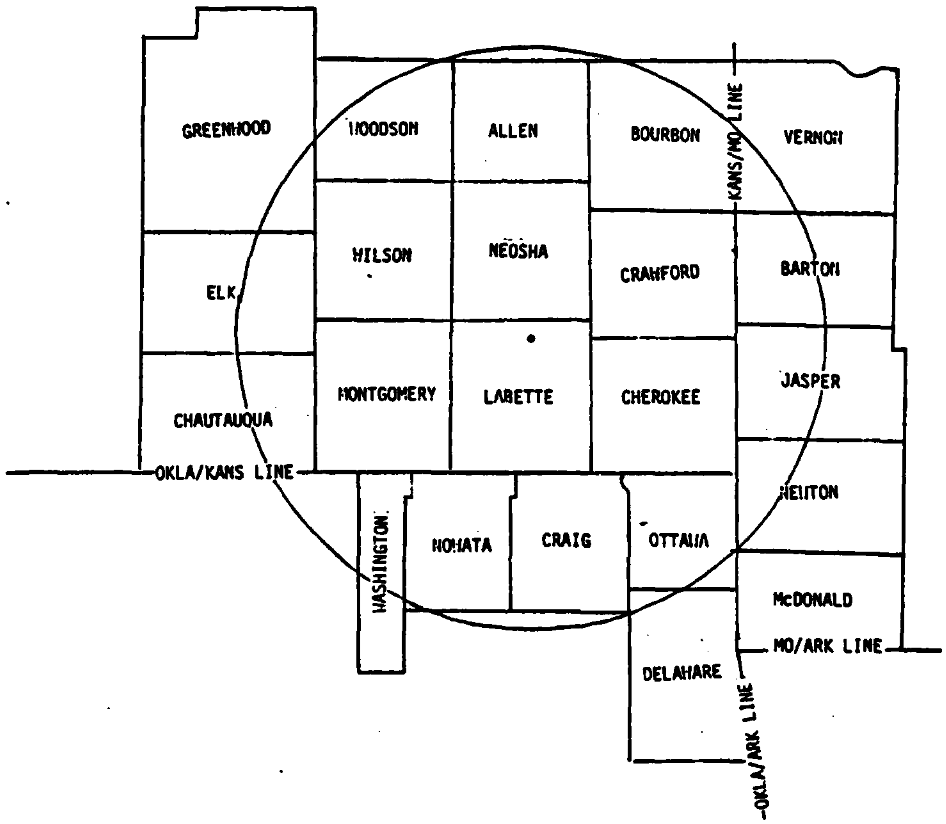


FIGURE 2-1. COUNTIES WITHIN A 50 MILE RADIUS OF KANSAS AAP

The cost of handling the wood chips at the KAAP boiler site was calculated for reference purposes only. This cost is $5.36/ton (Table 5-3).

c. Mill Residue. As shown in Table 7-1, the production of 1,000 board feet (Doyle Scale) of lumber generates more than four tons of mill waste. In October 1982, the Area Extension Forester and the Kansas Utilization Forester estimated that 11,200 tons of sawmill residue and 7,000 tons of pallet assembly residue was available within 50 miles of KAAP. It should be noted that this was all chippable waste (pieces) which generally has a higher value ($15 to $18 per ton) than sawdust and bark. However, Table 7-1 shows that the amount of sawdust and bark normally produced at the sawmill is approximately equal to the chippable waste (18,200 tons/year total for KAAP). Using the weights of Table 7-1, the amount of sawdust and bark represented by 18,200 tons/year of chippable residue (pieces) is: (18,200 tons/year)(4,680/3,780) = 22,533 tons/year.

Three sawmills within 25 miles of KAAP were visited in October 1982. These three mills each produce approximately 3,000 tons/year of mill residue (sawdust and bark). There are five additional mills within the 25 mile radius of the AAP each producing an estimated 3,000 tons/year of this mill residue. The mills identified and those visited are listed in Section 7-1.

The total sawdust and bark residues were found to be 22,533 tons/year (Gould estimate) and 24,000 tons/year (UAH estimate). The average of these two quantities is approximately 2/3 of the 36,000 tons/year required.

The cost of sawdust and bark in the vicinity of Kansas AAP was quoted at $5 to $7 per ton (1982 dollars). The costs of transporting and brokerage at the KAAP site are estimated to be $2.80 and $2.00 per ton, respectively (see Section 7-1). Thus, mill residue at a delivered cost of $11.80/ton results in an equivalent wood energy cost of (3)($11.80/ton) = $35.24 per ton which is competitive with the present cost of $42/ton delivered to Kansas AAP. Unfortunately, the quantity of this sawmill waste is inadequate for the MSR requirements.

If adequate wood waste was available for fuel at KAAP, the boiler site handling cost would be the same as that just presented for KAAP wood chips ($5.36/ton).

d. Fuelwood Plantation on Government Land. Approximately 750 acres at Kansas AAP are in woodlands. A 1981-1982 100% cruise performed by the area extension forester indicated that there was 302,561 board feet of marketable timber available (Appendix B). If this timber is marketed it would generate 2,178 tons of slash (Table 7-1). Also, there are many smaller trees that are available for fuel

wood and their utilization as fuel would be beneficial to forest management. Thus, a total of approximately 3,500 tons of fuelwood could be made available in 1983 by clear-cutting all of the on-site woodlands. However, this one-time harvest is obviously inadequate for the MSR fuel requirements (36,000 tons/year) so a fuelwood plantation would be the only on-site wood fuel production option.

Up to 9,000 acres of Kansas AAP land could be devoted to a fuelwood plantation. It is calculated in Section 8.3 that approximately 6,493 acres planted in fast-growing species would supply the boiler fuel required to produce the Minimum Sustaining Rate (MSR) steam requirements. This fuelwood was shown to cost $69.53/ODMT which is equal in energy to a coal cost of $88.01/ton. However, coal is available at KAAP at a delivered cost of $42/ton.

The cost of boiler site fuel handling would be $161,118/year or $7.75/ton (Section 8-3).

e. Processed Biomass Pellets. Processed biomasss pellets have been produced by some few firms in varying sizes to accomodate the fuel feed system of specific boiler installations. Because of the energy required to dry the biomass and form the pellets, they are usually considered only for replacement of the more expensive fuels. Generally, fuel pellets are not an economical replacement for coal (pellet cost is at least $50/ton) and at 8,000 Btu/lb, this is cost-competitive with $75/ton bituminous coal which contains 12,000 Btu/lb. The delivered cost of coal at KAAP is $42/ton. The cost of steam energy from these pellets is (75/42) = 1.786 times cost of the steam energy produced by coal at KAAP.

Guaranty Fuels, Inc. in Independence, Kansas is the nearest biomass fuel pellet producer and has a small pilot production line which runs intermittently. The pilot line does not produce the quantity of fuel pellets required by Kansas AAP even if the cost of $50/ton was acceptable. The nearest known large scale wood pellet fuel plant in operation is in Northern Florida and the cost of fuel from this plant would be $50/ton plus the cost of covered transportation. However, the Florida plant has already committed its output.

f. Agricultural Residue. Kansas produces about 300 million bushels of wheat, 200 million bushels of sorghum and 150 million bushels of corn annually. This crop production generates about 11 million tons of wheat straw and 11 million tons of stover from sorghum and corn annually (Section 9-1). In Kansas, it is much more common to bale wheat straw than stover, so straw would be a more practical fuel.

The wheat straw proposed for fuel at KAAP is baled at an average moisture content of 14% (see Chapter 9). However, the

moisture content typically increases to 20% before combustion and about 20% of the original fuel value is lost to deterioration in open storage (Section 9-1). Thus, 2.6 tons of straw or hay are required to replace one ton of coal so the KAAP straw fuel requirements for MSR are (2.6)(12,000 tons/year) = 31,200 tons/year (Section 9-1).

The delivered cost of wheat straw is $24.60/ton so the equivalent energy cost is (2.6)($24.60) = $63.96/ton. However, the delivered cost of coal at KAAP is $42/ton.

The boiler site handling cost of the straw calculated for reference purposes only is $10.92/ton (Section 9-1).

2-3 CONCLUSIONS

In order to better compare the true energy costs of the various biomass fuels to that of coal, all costs for Table 2-3 have been converted to $/MBTU of steam delivered by the central boiler plant (Sections 2-2 f., 5-3, 6-1, 7-1, 8-3 and 9-1). The most cost-effective biomass boiler fuel shown in Table 2-3 is mill residue, i.e., sawdust and bark ($1.84/MBTU), followed by off-site whole tree chips ($2.78/MBTU). However, there is an inadequate supply of mill residue. Therefore, it is not considered as a viable option to coal. Although agricultural residues are adequate, the lack of an existing collection system, the present use of this material for soil conservation and emergency animal food, and the storage problems will make utilization of agricultural residue unattractive. The off-site forest residue supply is marginal and the cost is too high for consideration. Wood fuel pellets are both inadequate in supply and too expensive at $3.91/MBTU.

The off-site supply of whole tree chips is adequate, but the cost is $2.78/MBTU, which is 27% higher than the cost of coal. An on-site fuelwood plantation could provide an adequate supply (if planted in the near future) at an estimated cost of $4.58/MBTU which is more than twice that of coal and is therefore not considered to be a cost effective option.

Of the several options (Table 2-3) available to Kansas AAP, off-site whole tree chips, agricultural residue, and on-site fuelwood plantations provide adequate biomass boiler fuel to meet peacetime (MSR) steam requirements. However, none of these options are cost effective when compared to coal. In addition, none of these options will provide adequate fuel for mobilization due to lead time necessary to produce or procure the additional quantities required in the time available. If biomass fuel should be chosen as the fuel for MSR operations, coal will have to be used to supplement biomass fuel during mobilization.

TABLE 2-3

SUMMARY OF FUEL OPTIONS AT KAAP*

Description of Option	Adequacy	Cost ($/MBTU/STEAM
Bituminous Coal	Adequate	2.19
Sawdust and Bark	Inadequate	1.84
Forest Residue (Slash)	Marginal	2.78
Agricultural Residue	Adequate	3.23
Existing AAP Forest	Inadequate	**
Off-site Whole Tree Chips	Adequate	2.78
AAP Fuelwood Plantation	Adequate	4.58
Wood Fuel Pellets	Inadequate	3.91

*Does not reflect differential boiler costs
**Quantity is too small for efficient harvesting

CHAPTER 3

MILAN ARMY AMMUNITION PLANT

The purpose of this study is to provide technical and economic data for determination of the feasibility of using biomass as an alternative boiler fuel at Milan Army Ammunition Plant (MAAP). Biomass fuel supply, costs and application are treated in subsequent sections of this report.

The objective of this study is to determine the long-term availability of solid biomass fuel to satisfy the steam demands at the AAP during peacetime (Minimum Sustaining Rate) and mobilization.

3-1 BACKGROUND

The Milan Army Ammunition Plant (AAP) is located near Milan, Tennessee in Gibson County. The Milan Plant has twelve production facilities which require high pressure steam (150 psig). The boilers at production Lines A, C, and E burn No. 6 fuel oil and the boilers at Lines B, F, X, and Z burn No. 2 fuel oil. These package type boilers are five to fifteen years old, having been replaced in the late 1960's or late 1970's. This type of boiler is unsuitable for conversion to fueling with coal or solid biomass. The remaining production facilities are served by a coal fired boiler house at Line K. These boilers were installed in 1941. A steam distribution system originates from the boiler house building at Line K and distributes steam to Lines D, H, O, J, and K. The production Lines A, C, B, X, and K operate during peacetime and mobilization. Lines E, F, and Z operate during mobilization periods only. Lines A and C do not require any steam during summer peacetime operation.

In addition, there are 24 small boilers generating steam at 15 psig for heating various non-production areas. The process lines and steam plant facilities are operated by Martin Marietta Aluminum Sales, Inc.

A study was conducted by Gilbert/Commonwealth, Engineers/Consultants (Reference 6) to recognize the problems associated with the existing steam/power systems and to develop a long-range, logical program for the steam/power system modernization to ensure preparedness to meet peacetime and mobilization requirements. This report identified the steam requirements for the total plant steam load to support all 12 production facilities and Line K boiler house steam loads to support production facilities at Lines D, H, O, J and K, as shown in Table 3-1.

TABLE 3-1

MILAN ARMY AMMUNITION PLANT
STEAM REQUIRED FOR PROCESS AND HEATING
(lb/hr)

Total Plant Operating (Including Line K)	Peacetime	Mobilization
Summer Average	30,000	65,000
Winter Average	71,300	138,300
Winter Peak (Estimated)	78,500	150,100

Line K Boiler House	Peacetime	Mobilization
Summer Average	25,200	53,300
Winter Average	39,200	75,100 lb/hr

Gilbert/Commonwealth estimated the annual MSR coal usage of Line K boiler as 9,860 tons delivered to the plant at a cost of $44.67 per ton. Wood supply required to generate 100% of the steam demand during peacetime (Minimum Sustaining Rate) and mobilization is as shown in Table 3-2.

TABLE 3-2

	Wood Required (As Received)			Acres of Forest to be Harvested	
	Tons/Hr	Tons/Day	Tons/Yr	Acres/Day	Acres/Yr
Peacetime	4.82	115.7	42,225	2.23	815
Mobilization	14.95	358.8	130,960	6.9	2,520

Gilbert/Commonwealth stated that if the price of fuel wood delivered to the plant was $12.50/ton or less then wood fuel costs would be equivalent to the coal price of $44.67/ton.

Gilbert/Commonwealth suggested that wood firing at Milan should not be considered. Although there was an adequate wood supply to support the plant, firing with wood is not economically feasible compared to coal.

The UAH team found that the Gilbert/Commonwealth wood cost of $12.50/ton was a rough estimate only but the delivered price of coal was correct at $44.67/ton. Also, the MSR wood fuel requirements should be (3.0)(9,860) = 29,580 tons/year (see Chapter 10).

3-2 BIOMASS SUPPLY SOURCES

The available biomass usable as boiler fuel within economical transportation distance of Milan AAP was identified as whole tree chipping, forest residue and mill residue. Whole tree sources included on-site and off-site woodlands. There are no processed biomass fuel pellets produced within hundreds of miles of Milan AAP and there is no adequate supply of agriculture residue. Farming in the area is on small plots and agriculture residue is primarily returned to the soil or used as animal feed. Figure 3-1 shows the Tennessee counties within a 50 mile radius of Milan AAP.

a. Whole Tree Chipping. West central Tennessee is heavily wooded and supports 20 sawmills and numerous pulp wood harvesting operations within 50 miles of Milan. Based on a 1979 TVA wood residue survey (Table 3-3), there are at least one million tons of trees harvested in this area annually (one ton of mill residue requires four tons of whole trees). Less than 4% of this amount is required for whole tree chips at MAAP. There is also adequate standing timber in the 7,000 acre on-site woodlands to provide a continuous wood fuel supply of 29,580 tons/year, the MSR requirement. However, most of the on-site timber is in small, widely dispersed stands, which makes whole tree chipping more difficult and increases harvesting costs.

Harvesting and transporting of whole tree chips at the AAP site are estimated to cost $17.24/ton including the cost of lost revenue from timber sales (stumpage cost) (see Section 5-4 a.). It is calculated that 3.0 tons of green wood are required to replace one ton of coal (see Chapter 10) so the equivalent wood energy cost is (3)($17.24) = $51.72/ton. If the whole tree chips were obtained off-site, the added cost of transportation would increase total cost to $18.71/ton or an equivalent wood energy cost of $56.13/ton (Section 5-4 b.). Neither of the above whole tree chip costs are competitive with coal delivered to MAAP at $44.67/ton.

The boiler site handling cost for wood chip fuel at MAAP, calculated for reference purposes only, is $6.64/ton (Table 5-6).

b. Forest Residue. Seven tons of forest residue (slash), i.e., the wood trimmed away from a saw log, is generated from the productin of each 1,000 board feet of lumber (Table 7-1). The timber being cut in the MAAP on-site woodlands will not provide enough slash to meet the daily peacetime fuel requirements and this quantity of

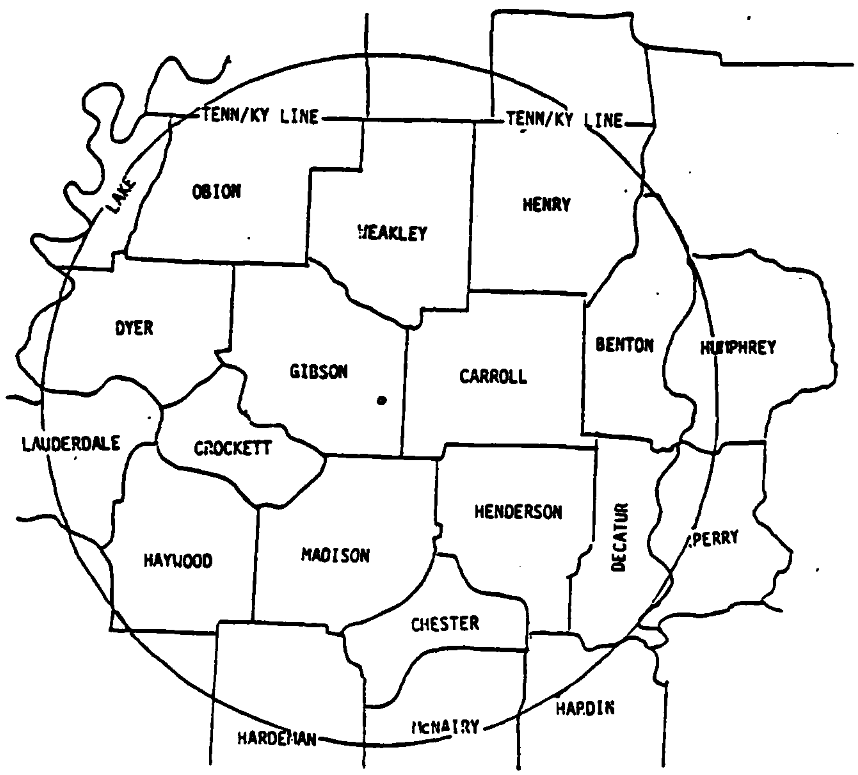


FIGURE 3-1. COUNTIES WITHIN A 50 MILE RADIUS OF MILAN AAP

slash would not be adequate even if the timber cutting was increased to the annual growth rate of the timber stand (Section 6-2). The slash produced by all of the logging operations within an economical (50 mile) transportation distance of the AAP is estimated to be about 500,000 tons/year and would more than adequately supply the peacetime fuel wood requirements if collected (Section 6-2). Currently there is no collection and chipping of slash in the area.

Chipping and transporting costs for slash chips obtained near the MAAP site are estimated to exceed $18.71/ton not including the cost of slash, if any (see Chapter 6). It is calculated that 3.0 tons of green wood are required to replace one ton of coal (see Chapter 10) which is an energy equivalent cost of (3)($18.71/ton) = $56.13/ton. These costs of chipping and transporting off-site slash are not competivive with the cost of coal at $44.67/ton delivered at Milan AAP.

The boiler site handling cost for wood chip fuel at MAAP, calculated for reference purposes only, is $6.64/ton (Section 6-2).

c. Mill Residue. The unused wood residue including mill residue from sources in the 16 counties within economical transportation distance, i.e. 50 miles, of the AAP was surveyed by the Land and Forest Resources Division of the Tennessee Valley Authority in 1979. The results of this survey are shown in Table 7-2. The fuels of primary interest are sawdust and bark which total 212,750 tons/year.

To complement the TVA wood residue data, the UAH team performed a separate survey of mill residue. There are about 20 sawmill and wood products firms within economical transportation distance of MAAP. In most cases, these operations sell their chippable residue to area paper or fiberboard mills for processing or fuel. Some of the sawdust is sold to Kentucky tobacco farmers and area turkey producers. However, a survey conducted in November 1982 as a part of ths study identified sources for 168 tons of sawdust and bark per day (see Table 7-3) which exceeds peacetime fueling requirements. Sawdust and bark were quoted at $6.50/ton (1982 dollars). Transportation and brokerage fee at the AAP site are estimated at $2.80/ton and $2.00/ton respectively. Total cost is estimated to be $11.30/ton (see Section 7-2). It is calculated that 3.0 tons of green wood are required to replace one ton of coal (see Chapter 10) so equivalent wood energy cost is (3)($11.30/ton) = $33.90/ton. The delivered cost of mill residue is competitive with coal at $44.67/ton delivered at Milan AAP.

d. Managed Energy Forest on Government Land. As stated earlier, there are 7,000 acres of woodlands at Milan AAP. These consist of hardwood timber of a random mix and are presently undersized for maximum sawtimber value. Thus sawlog revenues should increase in

a few years as trees mature. The Milan AAP woodlands management plan provides for periodic hardwood timber sales, the most recent being 1978. In addition to the hardwood stands there are pine stands which are currently being sold for pulpwood.

Utilization of either the existing 7,000 acres of woodlands or other acres currently leased for row-crops or grazing could provide adequate fuelwood for peacetime operation. In 1982, 4,202 acres were leased out for row crops and 9,019 acres for grazing. Native trees or fast growing species could be planted on some of these 13,221 total acres now leased but at some penalty to the Land Management revenues (see Section 8-4). A total of 5,335 acres would have to be set aside for this new fuelwood plantation to provide MSR fuelwood (Section 8-4).

Therefore, there are two possible scenarios for supplying the required fuelwood from on-site MAAP land. The first is for the 7,000 acre existing conventional on-site forest to be converted to a fuelwood plantation wherein use of this wood as fuel could be started at once. This is no particular advantage since the fuelwood supply will not be required until about 1987 when boiler conversion and handling facilities can be completed. This standing timber could be used as whole trees for chipping (Section 5-4). This option is not desirable because:

- o The forest is already under a management plan to provide soil conservation and salable timber.
- o The individual tree stands are generally small and scattered, making whole tree chipping difficult.
- o The existing tree varieties and spacings are not optimal for fuel purposes.
- o Eventually (in 15-20 years), the large tree stumps would have to be uprooted which is an expensive operation compared to uprooting a planned energy forest which has much smaller stumps.

If all of these factors are ignored, the delivered cost of on-site whole tree chips is $17.24/ton with an equivalent wood energy cost of $51.72/ton (see Section 5-4 a.). This cost is not competive with the delivered cost of coal of $44.67/ton at MAAP.

The boiler site handling cost for on-site wood chip fuel at MAAP, calculated for reference purposes only, is $6.64/ton (Section 5-4 a.).

The second MAAP on-site wood fuel option is a new energy plantation. If started now, this system could produce adequate fuel in four to five years from a total of about 5,335 acres, which are available. However, this option is also too costly (see Section 8-4). This fuel is estimated to have a delivered cost equivalent to coal costing $90.57/ton which is not competitive with coal available at $44.67/ton.

The boiler site handling cost for energy plantation derived wood fuel at MAAP is $9.37/ton (Section 8-4).

e. Processed Biomass Pellets. Processed biomass pellets have been produced in varying sizes to accomodate the fuel feed systems of specific boiler installations. As of January 1983 there was only one U.S. operating plant producing biomass pellets and its output was not sufficient to consider using pellets at Milan AAP. Also, biomass fuel pellets are not a cost-effective alternative to coal.

f. Agricultural Residue. The farming around MAAP was noted by the UAH field survey to occur mostly on small plots of land. In traveling several hundred miles on rural roads to survey the area, the UAH team found no evidence of baling of stover and only a few round bales of hay or straw. There was no Tennessee State data available on crop residues for the area around MAAP, so the field survey was the primary reason for deciding that the residue was inadequate in quantity for fuel purposes. However, there was recent data on hay prices for Tennessee (Section 9-2). These data show that the average annual cost of hay should be in excess of $46/ton, so even if the inadequacy of the supply indicated by the UAH survey is not correct, agricultural residue would be much too expensive for boiler fuel use. Therefore, no more consideration was given to this type of fuel at MAAP (Section 9-2).

3-3 CONCLUSION

Table 3-3 gives a summary of fuel options at Milan AAP. In order to better compare the true energy costs of producing steam with the various biomass fuels to the cost of steam from coal, all costs have been converted to $/MBTU of steam required from the central boiler plant (Sections 5-4, 6-2, 7-2, 8-4 and 9-2). Mill residue (sawdust and bark), forest residue, on-site tree plantations and existing forests both on and off-site provide adequate biomass boiler fuel to meet peacetime (MSR) steam requirements. The most cost effective biomass boiler fuel in adequate supply is mill residue, i.e., sawdust and bark, which can be supplied at about $1.77/MBTU Steam. Mill residue is the preferred Milan AAP biomass boiler fuel in adequate supply to furnish peacetime (MSR) steam requirements for the new

central boiler house. None of the other options are cost effective when compared to coal ($2.33/MBTU Steam).

In addition, none of the options will provide adequate fuel for mobilization due to lead time to produce or procure the additional quantities required in the time available. Coal will have to be used to supplement biomass fuel during mobilization if biomass fuel is chosen for MSR operations.

TABLE 3-3

SUMMARY OF FUEL OPTIONS AT MAAP*

Description of Option	Adequacy	Cost ($/MBTU/STEAM
Bituminous Coal	Adequate	2.33
Sawdust and Bark	Adequate	1.77
Forest Residue (Slash)	Adequate	3.07
Agricultural Residue	Inadequate	N/A
Existing AAP Forest	Adequate	2.69
Off-site Whole Tree Chips	Adequate	2.92
AAP Fuelwood Plantation	Adequate	4.72
Wood Fuel Pellets	Unavailable	N/A

*Does not reflect differential boiler costs

CHAPTER 4

INDIANA ARMY AMMUNITION PLANT

The purpose of this study is to provide technical and economical data for determination of the feasibility of using biomass as an alternative boiler fuel stock at Indiana Army Ammunition Plant (IAAP). Biomass supply, costs and application are treated in subsequent sections of this report.

The objective of this section of the study is to determine the long term availability of solid biomass fuel to satisfy the steam demands at the IAAP during peacetime (Minimum Sustaining Rate) and mobilization.

4-1 BACKGROUND

A "Steam/Power Plant Modernization Program for Indiana Army Ammunition Plant" was published by Sanders and Thomas, Inc. in July 1982 (Reference 7). The values for steam demand and fuel requirements contained in this report were inconsistent.

The fuelwood requirements used herein were based on a Load, Assemble and Pack (LAP) area annual oil consumption of one million gallons of fuel oil. Green fuelwood required to supply the equivalent of that quantity of fuel oil was calculated by UAH to be 17,500 tons annually (Section 5-5). No Sanders & Thomas estimate of the fuelwood requirement was available.

The propellant and explosive (P&E) area of Indiana AAP is inactive and it is not anticipated that it would be reactivated except in the case of a mobilization. Therefore, the P&E fuel requirements were not included in this study.

4-2 SITE DESCRIPTION

The Indiana Army Ammunition Plant (IAAP) is located near Charlestown, Indiana in close proximity to Louisville, Kentucky. The plant is bounded on the west by Indiana Highway 62 and on the east by the Ohio River. The 10,500 acre facility is divided into three distinct steam distribution areas: the Propellant and Explosives (P&E) Area, the Black Power Manufacturing Area, and the Load, Assemble and pack (LAP) Area. Steam is generated in 23 locations throughout the three plant areas. The area to be served by the proposed coal-fired LAP Area central steam plant consists of load lines, igniter lines, main change house, administration area and inert storage area. These areas were all served by separate oil-fired equipment found to be in good operating condition but not suitable for conversion to coal or biomass fuel use.

4-3 BIOMASS SUPPLY SOURCES

The available biomass usable as boiler fuel within economical transportation distance (50 miles) of Indiana AAP was identified as whole tree chipping, forest residue, mill residue and agricultural residue. Whole tree chipping included on-site and off-site woodlands. There are no processed biomass fuel pellets produced within hundreds of miles of Indiana AAP. Figure 4-1 shows the Indiana counties within 50 miles of Indiana AAP.

Southern Indiana has both State and National Forests as well as commercial forests. The area within economical transportation distance (50 miles) of the IAAP supports 67 sawmills and wood products industries. According to USDA Forest Service Resource Bulletin NC-20, this area produced 31 million board feet of lumber in 1971. This is equivalent to about 279,000 tons of logs and 223,000 tons of slash (Chapter 7). There is a profusion of Virginia Pine in Clark State Forest and Hoosier National Forest as well as a variety of hardwoods. The Virginia Pines were planted during the early 1930's to provide pulpwood for a paper mill which has since closed. There is little or no market for the Virginia Pines in commercial, state or national forests and the public prefers hardwood for residential fireplaces.

a. Whole Tree Chipping. There are 2,800 acres of woodlands on-site where logging is permitted. These trees consist of walnut, white oak, and pine and are of insufficient quantity to supply wood fuel requirements. Also, much of this wood is too valuable to be chipped 100% for fuel. Finally, approximately half of these acres are up for sale and will not be available in the future. Therefore, study of this source of wood fuel was discountinued.

Although there is an adequate supply of timber on private and off-site government woodlands which could be whole tree chipped to supply fuelwood for the AAP, it is not cost competitive with coal. The most recent cost of coal (late 1982) was $49/ton. The costs of harvesting and transporting off-site wood chips at the Indiana AAP, including the cost of timber, are estimated at $19.65 per ton (see Section 5-5). It is calculated that 3.0 tons of green wood are required to replace one ton of coal (see Chapter 10). Thus, the cost of wood fuel as compared to coal is (3)($19.65) = $58.95/ton whereas coal is available at $49/ton.

The boiler site handling cost for off-site wood chip fuel at IAAP, calculated for reference purposes only, is $11.22/ton (Section 5-5).

b. Forest Residue. The number of logging operations required to support the numerous sawmills within the area of interest

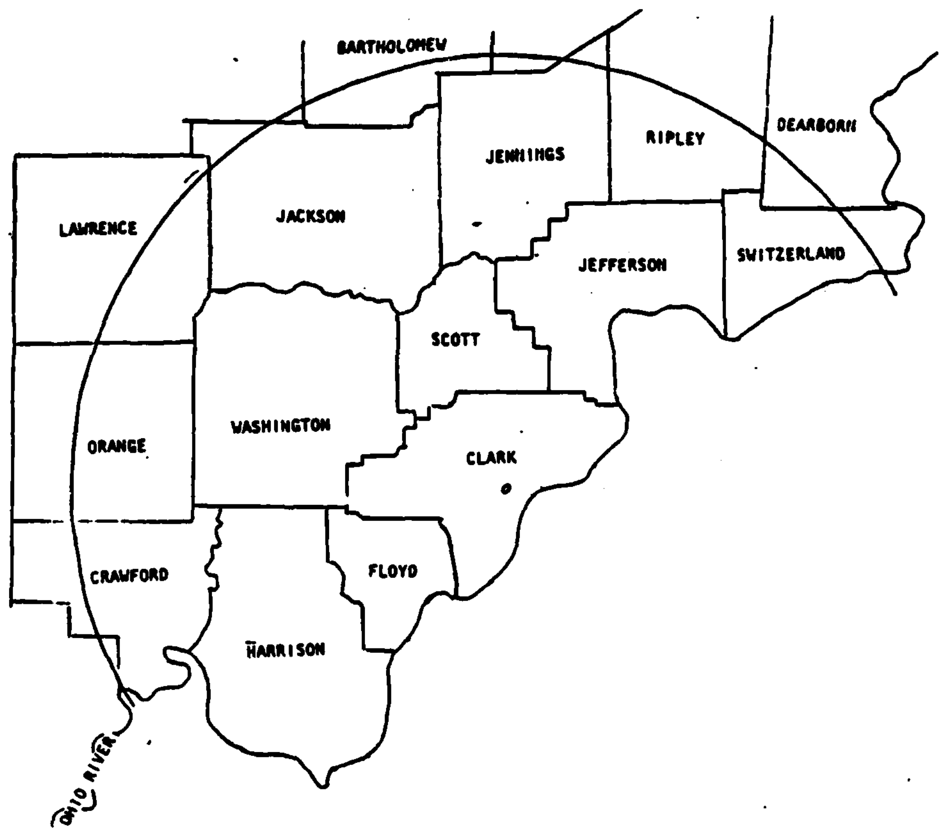


FIGURE 4-1. COUNTIES WITHIN A 50 MILE RADIUS OF INDIANA AAP

near the AAP indicates that the forest residue (slash) is adequate to supply the fuelwood requirements. Approximately 50% of the forest residue is being absorbed as residential firewood and the remainder is not being collected. Based on a USDA Forest Service Report, this remainder should be at least 111,000 tons/year.

From Section 6-2, the equivalent cost of off-site slash chips is (3)($19.65) = $58.95/ton. Although the quantity of forest residue appears to be adequate, if collected, chipped and transported it is not cost competitive with coal (quoted at $49 per ton).

The boiler site fuel handling cost is the same as for off-site whole tree chips - $11.22/ton (Section 6-3).

c. Sawmill Residue. Data provided by Indiana State Forestry Commission lists 67 sawmills and wood products industries in the eight Indiana counties surrounding the AAP. The State Utilization Forester (Mr. Don McGuire) listed 14 larger sawmills in the area which would be potential suppliers of mill residue. Nine of the 14 were visited in December 1982 (see Section 7-3).

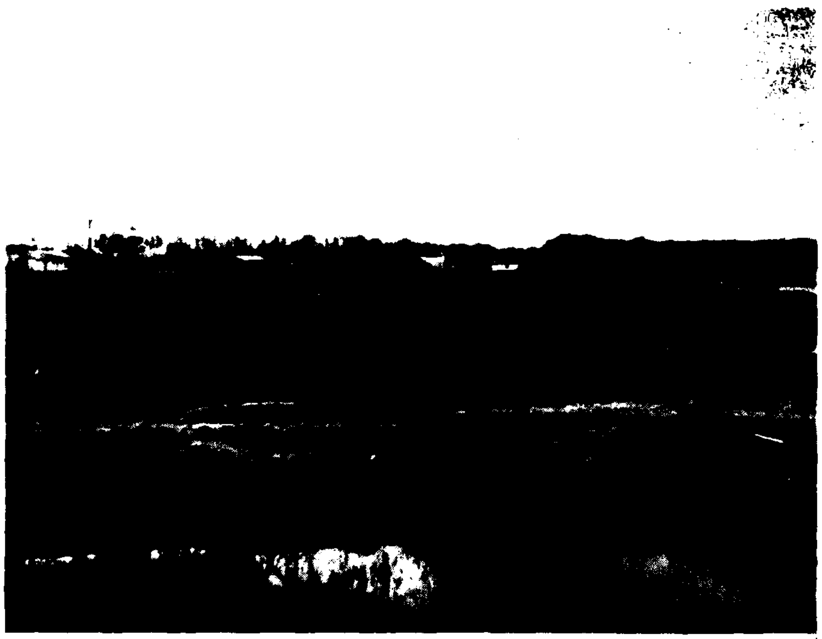
Each sawmill visited was producing an average of 20 to 22 tons of sawdust and bark per work day (five days/week) and most were selling and hauling the residue (and chips in some cases) to Willamette Paper Company at Hawesville, Kentucky. Hauling distances were from 90 to 140 miles. Each complained that the price paid for bark and sawdust (quoted as $7.90/ton in one case only) just about covered transportation cost. Each indicated an interest in hauling mill residue to Indiana AAP at the same price due to the reduced distance, (not greater than 50 miles). Using two different methods, the UAH estimate of sawdust and bark production was 70,000 tons/year and 167,500 tons/year (Section 7-3). Even 1/3 of the lower estimate would provide more than the IAAP MSR fuelwood requirement (17,500 tons/year).

It is interesting to note that three of the mills visited were storing and or giving away sawdust and bark because of the low prices paid for this material at Hawesville. These and other mills had up to 10 years accumulation of sawdust and bark in piles. Pictures were taken of the larger piles at DeHart, Burton and Baxter sawmills. The Baxter pile represented about 50,000 tons accumulation. The DeHart and Burton piles were roughly of the same magnitude (see Figures 4-2 and 4-3).

The delivered cost of sawmill waste fuel at IAAP is $9.90/ton (Section 7-3). The coal equivalent of this cost is (3)($9.90/ton) = $29.70/ton. This is considerably cheaper than the latest quoted coal costs of $49/ton.

FIGURE 4-2

50,000 TON SAWMILL WASTE PILE AT DeHART (INDIANA) SAWMILL



View of Waste Pile Looking West

View of Waste Pile Looking North

FIGURE 4-3

50,000 TON SAWMILL WASTE PILES AT BURTON AND BAXTER SAWMILLS

Baxter Sawmill, Deputy, Indiana

Burton Sawmill, Blocher, Indiana
(Pile extends to lumber stack at left)

The cost of handling the sawmill waste at the IAAP boiler site would be the same as for wood chip fuel - $11.22/ton (Section 7-3).

d. Managed Fuelwood Plantations on Government Land. There are approximately 2,800 acres of woodlands on-site and approximately 1,400 acres of this land are being offered for sale. The trees in these woodlands consist mostly of walnut and white oak and are generally of more value as sawlogs than fuelwood. The 1,400 acres remaining after the sale can only supply a fraction of the 17,500 tons/year of fuelwood required because the annual growth rate is only three to five green tons/year.

An additional 2,000 acres, currently leased for grazing, could be planted as an on-site energy forest (fuelwood plantation). A 2,000 acre energy forest could provide about two-thirds of the fuelwood required annually to fuel the new LAP central steam plant (see Section 8-5).

In conclusion, the only way that an adequate fuelwood plantation could be created at IAAP would be to cut down and uproot the existing forest, which would be too costly to consider. Therefore, the cost of a fuelwood plantation was not calculated.

e. Agricultural Residue. The amount of agricultural residue required for IAAP MSR fuel requirements is 15,166 tons/year which is about 50% of the collectible residue in the area. It is doubtful that existing equipment is available to collect this much farm residue. If it could be collected, the farm residue would cost an average of $55.60/ton which is equivalent to coal costing (2.6)($55.60/ton) = $144.56/ton whereas coal is available delivered to IAAP at $49/ton (Section 9-3).

The boiler site handling cost of agricultural residue fuel at IAAP is estimated to be $22.40/ton (Section 9-3).

4.4 CONCLUSION

In order to better compare the true energy costs of producing steam with the various biomass fuels to the cost of steam from coal, all costs have been converted to $/MBTU of steam required from the central boiler plant in the LAP area (Sections 5-5, 6-3, 7-3, 8-5 and 9-3). These steam energy costs are shown in Table 4-1.

Of the several options available to Indiana AAP, off-site whole tree chips, sawdust and bark, forest residue and agricultural residue provide adequate biomass boiler fuel to meet the peacetime (MSR) requirements for the new LAP boiler house (Section 4-1).

However, agricultural residue is listed as marginal because of the probability that the existing on-farm collection system may not be able to meet the fuel requirements and the farmers may be unwilling to divert 50% of their residue from traditional uses.

The most cost-effective biomass boiler fuel is sawmill residue, i.e., sawdust and bark ($1.55/MBTU Steam). Although forest residue could provide an adequate supply of fuel there is no known harvesting system currently operational and it would not be cost-effective at $3.07/MBTU Steam.

The off-site whole tree chip supply is the same cost as forest residue and would also require establishment of a harvesting system.

None of the options will provide adequate biomass fuel for mobilization because of the lead time necessary to produce or procure the additional quantities needed after mobilization begins. If biomass fuel is chosen as the primary fuel for MSR operation, coal should be used as a supplemental fuel if mobilization occurs.

TABLE 4-1

SUMMARY OF FUEL OPTIONS AT IAAP*

Description of Option	Adequacy	Cost ($/MBTU/STEAM
Bituminous Coal	Adequate	2.56
Sawdust and Bark	Adequate	1.55
Forest Residue (Slash)	Adequate	3.07
Agricultural Residue	Marginal	7.52
Existing AAP Forest	Inadequate	**
Off-site Whole Tree Chips	Adequate	3.07
AAP Fuelwood Plantation	Inadequate	N/A
Wood Fuel Pellets	Unavailable	N/A

*Does not reflect differential boiler costs
**Quantity too small for efficient harvesting

CHAPTER 5

WHOLE TREE CHIPPING

Whole tree chipping is a term used to describe an operation where trees are cut down and the entire tree is reduced to chips in order to be used as boiler fuel or in some conversion process. Whole tree chipping may occur when wooded areas are clear cut to provide open land for farming or building construction. It also can occur during the thinning out of a forested area to improve the growth of the remaining trees or when selected trees are cut for whatever reason. Generally, these sources of whole tree chips cannot be depended upon as long-term off-site supplies.

Whole tree chipping would also be used during the harvesting of energy forests (fuelwood plantations). However, the whole tree chipping operation involved with the small diameter trees from fuelwood plantations is considerably different from that used with mature existing forests on-site or off-site at the AAPs. In this study, whole tree chipping operations refer only to mature forests, except as noted.

The harvesting and transportation equipment required for mature whole tree chipping is:

- whole tree chipper
- feller buncher
- grapple skidder
- logger-forwarder
- maintenance and fuel truck
- knife grinder
- chip semitrailer (van)
- chainsaw

This list represents the <u>maximum</u> types of equipment to be used. Some items may not be necessary depending on tree size, specie, spacing, terrain and other factors.

The whole tree chipper should be sized appropriately to the trees to be chipped. In a mature forest or woodland area, a whole tree chipper capable of accepting tree trunk diameters of 20" or more may be required. For the few trees encountered that are larger than 20" in diameter, chainsaws are used to reduce trees to chipping size. On fuelwood plantations, a whole tree chipper capable of accepting five inch to six inch diameters or less may be adequate. The capital cost of the chippers will vary with size as will the fuel used and the daily output in tons.

The feller-buncher, grapple skidder and logger-forwarder also must be sized to the chip throughput requirements. The maintenance and fuel truck, knife grinder, chip van and tractor truck are of standard size and will not vary with the rate of chipping. The number of chip vans and tractors required will depend upon the number of tons of chips required to be delivered to the fuel pile each day and the distance from the harvesting site and the fuel pile.

To determine the cost of whole tree chipping, it is necessary to find the cost of appropriately sized harvesting equipment and the quantity needed to meet daily fuelwood demands. Only 200 operating days out of a normal workyear of 250 days should be used in the calculations to allow for bad weather conditions at all three AAP sites. To compensate for the reduced workdays per year, a 10-hour workday is assumed.

Table 5-1 details the assumptions and calculations used in preparing the whole tree chip expense sheets (Tables 5-2 through 5-8). It may be seen that these assumptions and calculations follow standard industrial practice in computing total system costs. In the case of fixed equipment operations on a Federal reservation (Boiler Site Equipment, Tables 5-3, 5-6 and 5-8), the rationale for total life cycle cost analysis may be somewhat different. However, the breakdown of costs on these tables is such that a different cost analysis rationale may easily be accomplished. Possibly, the average annual fixed costs (second column from left) might be deleted as a total cost component.

Transportation fuel costs are a function of the distance from the harvesting operation and the fuel pile and the number of trips required to meet required tonnage. A normal van load is 20 to 23 tons. Tractor trucks used to haul loaded vans average 5.0 miles/gallon. Return trips (empty) average about 7.0 miles/gallon.

Table 5-2 gives a harvesting equipment selection which will provide a maximum of 44,000 tons per year of wood chips (actual requirement is 36,000 tons/year).

Transportation distances off-site for each AAP will be approximately the same. Based on delivery within a 35 mile radius or 70 mile round trip, the transportation costs are also shown in Table 5-2 for the 36,000 ton/year case.

TABLE 5-1

ASSUMPTIONS MADE FOR WOOD HARVESTING, TRANSPORTATION AND HANDLING COSTS

1. Fixed costs = depreciation + interest + insurance + principle + miscellaneous expenses

   Depreciation is based upon an average life of five years using straight line depreciation with 30% salvage value (average 14%/year of equipment price).

   Interest is based upon 80% financing over five years with monthly installment payments at an effective rate of 18% per year. No interest is paid on the 20% down payment assumed (average 8.3%/year of equipment price).

   Insurance is based on replacement value and is calculated as $3.00 per $100 per year on the original cost of the equipment (average 3%).

   Miscellaneous expenses include administrative costs, taxes, rents, etc. (average 6.8%).

   Annual fixed costs averaged 32% of the original price of the equipment.

   The harvesting equipment data is based on case study information from Morbark Industries, Inc.

2. Maintenance costs are scaled from capital cost and average 10.9% of original cost per year over a five-year period.

3. There are 200 operation days out of 250 days per year due to bad weather conditions.

4. Fuel cost is $1.10 per gallon of diesel fuel. The harvesting equipment and transportation fuel costs are calculated as a function of horsepower (see item 9).

5. Labor averages $10/hour which includes all fringe benefits.

6. Tractor truck fuel cost is based on 70 mile round trip and 800 trips per year - truck. These diesel trucks average 6 miles/gallon.

7. All of the equipment in the expense statement is purchased new. Of course, in reality, some portion will probably be used equipment.

8. Fixed, maintenance, and labor costs are scaled as a function of the capital cost of each particular piece of equipment. Note that some costs may vary from the average scaled factors due to variances in equipment usage.

9. Fuel cost information for fixed equipment was determined according to the following conversion factors:

   Fuel consumption rate for Diesel engine:

   Gallons per hour = 0.40 x 0.65/7.08 x hp = 0.037 x hp

   Fuel consumption rate for gasoline engine:

   Gallons per hour = 0.46 x 0.65/6.01 x hp = 0.050 x hp

   Where: .40 = pounds of Diesel fuel consumed per hp hr
   .46 = pounds of gasoline fuel consumed per hp hr
   7.08 = weight (lb) of Diesel fuel per gallon
   6.01 = weight (lb) of gasoline per gallon

   Hourly fuel cost for Diesel engine:

   0.037 x hp x cost/gallon

   Hourly fuel cost for gasoline:

   .050 x hp x cost/gallon

10. In calculating labor costs, we assume a 10 hour workday with each worker drawing approximately $20,000/year (including fringes).

11. Transportation fuel costs are based on six mpg for both 20-mile roundtrips and 70-mile roundtrips.

12. The average chip van load size is 23 tons.

13. In calculating fuel cost for electrically powered machinery, we used .7457 kW = 1 hp as our conversion factor. We assume the machine operates at 50% capacity (capacity being 2,000 hrs/yr) at $.04/kW hour.

14. The values assigned for stumpage and profit were estimated averages and are intended to convey the fact that such costs should be taken into consideration when calculating an overall cost figure.

TABLE 5-2

EQUIPMENT EXPENSE SHEET FOR HARVESTING AND TRANSPORTING 36,000 TONS/YEAR OF WHOLE TREE CHIPS FROM FIELD TO PILE (LONG RUN - 70-mile round-trip)

	Price	Avg. Annual Fixed Costs	Average Annual Maint./Yr	Avg.Fuel Cost/Yr	Labor Cost/Yr	Approximate Fuel Cost Per Ton	Total Cost	Power	Recommended Economic Life (Yrs)	Characteristics
HARVESTING EQUIPMENT										
1 Morbark Model 20 whole tree chipper	$135,000	$43,200	$14,715	$ 28,490	$ 55,752	$0.79	$142,157	350 hp	5	20" max. tree diameter, 200-300 tons/shift 7-10 yr. oper. life
2 feller bunchers	80,000	25,766	8,720	6,838	33,038	0.19	74,362	42 hp ea.	5	13" max. tree dia., quickly lightwt. 300 tons/shift 15-20 yr. oper.life
3 chainsaws	900	144	49	611	371	0.02	1,175	2.5 hp. ea.	1	
1 grapple skidder	67,500	21,741	7,377	6,512	27,880	0.18	63,510	80 hp	4	300 tons/shift, 5-10 yr. oper. life
1 logger-forwarder to chipper	35,000	11,273	3,825	3,419	14,456	0.09	32,973	42 hp	5	To feed the chipper 300 tons/shift,10-15 yrs.
1 maintenance and fuel truck	15,000	4,831	1,639	4,477	6,195	0.12	17,142	55 hp		12 yr. oper. life
1 knife grinder	6,000	1,932	656	814	2,478	0.02	5,880	10 hp	4	25 yr. oper. life, replace grinding stone
Sub-Total	$338,950	$108,887	$36,981	$ 51,161	$140,170		$337,199			
Cost/Ton		$3.02	$1.03	$1.42	$3.89	$1.41	$ 9.37			
TRANSPORTATION										
4 chip trailers	$ 80,000	$ 26,000	$ 8,000	-----	-----	----	$ 34,000	0	4	Standard floor 27,000 tons/year; 54,000 lb payload, 7-9 yr. oper. life
2 tractor trucks	150,000	37,000	17,000	20,533	40,000	0.57	114,533	350 hp ea.	5	10 yr. oper. life
Sub-Total	$230,000	$ 63,000	$25,000	$ 20,533	$ 40,000		$148,533			
Cost/Ton (C/T)	$6.38	$1.75	$0.69	$0.57	$1.11	$0.57	$4.13			
TOTAL COSTS	$568,750	$171,887	$ 61,981	$71,713	$159,998		$485,732			
Total Operation C/T		$4.77	$1.72	$1.99	$4.44	$1.98	$13.50			
Stumpage C/T							$ 2.20			
Profit C/T							$ 2.00			
GRAND TOTAL C/T DELIVERED							$ 17.70			

TABLE 5-3

EQUIPMENT EXPENSE SHEET FOR HANDLING 36,000 TONS/YEAR OF WHOLE TREE CHIPS AT THE BOILER SITE

	Price	Avg. Annual Fixed Costs	Average Annual Maint./Yr	Avg.Fuel Cost/Yr	Labor Cost/Yr	Approximate Fuel Cost Per Ton	Total Cost	Power	Recommended Economic Life (Yrs)	Characteristics
BOILER SITE EQUIP.										
1 Truck Dump	$ 50,000	$ 16,000	$ 5,450	$ 3,830	$ 10,000	$0.11	$ 35,280	50 hp elec.	5	Cost includes hydraulic lift & foundations labor, 25-30 yr. oper. life 50 tons capacity
1 Hog	30,000	9,600	3,270	11,930		0.33	24,800	400 hp	5	
1 live bottom hopper	70,000	22,400	7,630	4,600	5,000	0.14	39,630	30 hp elec.	5	3 tons/minute 15-20 yr. oper. life
1 bulldozer	85,000	27,200	9,265	15,600	21,360	0.46	73,425	200 hp	5	10 yr. oper. life
1 metal detector	5,000	1,600	545	300	1,260	0.01	3,705	Approx. 1 kW	5	25 yr. oper. life
1 conveyor to storage	9,000	2,880	981	3,060	2,260	0.09	9,181	20 hp elec.	5	50' long/3 tons/min. 5 yr. oper. life
1 disc screen	13,000	4,160	1,417	1,530	3,270	0.05	10,377	10 hp elec.	5	3 tons/minute 5-10 yr. oper. life
Total	$262,000	$ 83,840	$28,558	$ 40,850	$ 43,150		$196,398			
Cost/Ton							5.46/Ton			

TABLE 5-4

EQUIPMENT EXPENSE SHEET FOR HARVESTING AND TRANSPORTING 29,580 TONS/YEAR OF WHOLE TREE CHIPS FROM FIELD TO PILE (SHORT RUN - 20-mile round-trip)

	Price	Avg. Annual Fixed Costs	Average Annual Maint./Yr	Avg.Fuel Cost/Yr	Labor Cost/Yr	Approximate Fuel Cost Per Ton	Total Cost	Power	Recommended Economic Life (Yrs)	Characteristics
HARVESTING EQUIPMENT										
1 Morbark Model 20 whole tree chipper	$135,000	$43,200	$14,715	$ 28,490	$ 47,794	$0.96	$134,199	350 hp	5	20" max. tree diameter, 200-300 tons/shift 7-10 yr. oper. life
2 feller bunchers	80,000	25,766	8,720	6,838	28,323	0.23	69,647	42 hp ea.	5	13" max. tree dia., quickly lightwt. 300 tons/shift 15-20 yr. oper.life
3 chainsaws	450	144	49	611	159	0.02	963	2.5 hp ea.	1	
1 grapple skidder	67,500	21,741	7,377	6,512	23,897	0.22	59,527	80 hp	4	300 tons/shift, 5-10 yr. oper. life
1 logger-forwarder to chipper	35,000	11,273	3,825	3,419	12,391	0.12	30,908	42 hp	5	To feed the chipper 300 tons/shift, 10-15 yrs.
1 maintenance and fuel truck	15,000	4,831	1,639	4,477	5,310	0.15	16,257	55 hp		12 yr. oper. life
1 knife grinder	6,000	1,932	656	814	2,124	0.03	5,526	10 hp	4	25 yr. oper. life, replace grinding stone
Sub-Total	$338,950	$108,887	$36,981	$ 51,161	$119,998		$317,027			
Cost/Ton		$3.68	$1.25	$1.73	$4.06	$1.73	$10.72			
TRANSPORTATION										
2 chip trailers	$ 40,000	$ 13,000	$ 4,000	-----	-----	----	$ 17,000	0	4	Standard floor 27,000 tons/year; 54,000 lb payload, 7-9 yr. oper. life
1 tractor truck	75,000	18,500	8,500	4,767	20,000	0.16	51,767	350 hp ea.	5	10 yr. oper. life
Sub-Total	$115,000	$ 31,500	$12,500	$ 4,767	$ 20,000		$ 68,767			
Cost/Ton		$1.06	$0.42	$0.16	$0.68	$0.16	$2.32			
TOTAL COSTS	$453,950	$140,387	$49,481	$ 55,828	$139,998		$385,794			
Total Operation C/T		$4.74	$1.67		$4.74	$1.89	$13.04			
Stumpage C/T							$ 2.20			
Profit C/T							$ 2.00			
GRAND TOTAL C/T DELIVERED							$17.24			

TABLE 5-5

EQUIPMENT EXPENSE SHEET FOR HARVESTING AND TRANSPORTING 29,580 TONS/YEAR OF WHOLE TREE CHIPS FROM FIELD TO PILE (LONG RUN - 70-mile round-trip)

	Price	Avg. Annual Fixed Costs	Average Annual Maint./Yr	Avg.Fuel Cost/Yr	Labor Cost/Yr	Approximate Fuel Cost Per Ton	Total Cost	Power	Recommended Economic Life (Yrs)	Characteristics
HARVESTING EQUIPMENT										
1 Morbark Model 20 whole tree chipper	$135,000	$43,200	$14,715	$ 28,490	$ 47,794	$0.96	$134,199	350 hp	5	20" max. tree diameter, 200-300 tons/shift 7-10 yr. oper. life
2 feller bunchers	80,000	25,766	8,720	6,838	28,323	0.23	69,647	42 hp ea.	5	13" max. tree dia., quickly lightwt. 300 tons/shift 15-20 yr. oper.life
3 chainsaws	900	144	49	611	159	0.02	963	2.5 hp ea.	1	
1 grapple skidder	67,500	21,741	7,377	6,512	23,897	0.22	59,527	80 hp	4	300 tons/shift, 5-10 yr. oper. life
1 logger-forwarder to chipper	35,000	11,273	3,825	3,419	12,391	0.12	30,908	42 hp	5	To feed the chipper 300 tons/shift, 10-15 yrs.
1 maintenance and fuel truck	15,000	4,831	1,639	4,477	5,310	0.15	16,257	55 hp		12 yr. oper. life
1 knife grinder	6,000	1,932	656	814	2,124	0.03	5,526	10 hp	4	25 yr. oper. life, replace grinding stone
Sub-Total	$338,950	$108,887	$36,981	$ 51,161	$119,998		$317,027			
Cost/Ton	$11.45	$3.68	$1.25	$1.73	$4.06	$1.73	$10.72			
TRANSPORTATION										
4 chip trailers	$ 80,000	$ 26,000	$ 8,000	-----	-----	----	$ 34,000	0	4	Standard floor 27,000 tons/year; 54,000 lb payload, 7-9 yr. oper. life
2 tractor trucks	150,000	37,000	17,000	16,683	40,000	$0.56	111,983	350 hp ea.	5	10 yr. oper. life
Sub-Total	$230,000	$ 63,000	$25,000	$ 16,683	$ 40,000		$145,983			
Cost/Ton	$7.77	$2.13	$0.85	$0.56	$1.35	$0.56	$3.79			
TOTAL COSTS	$568,950	$171,887	$ 76,696	$108,160	$159,998		$463,010			
Total Operation C/T		$5.81	$2.10	$2.29	$6.08	$2.29	$14.51			
Stumpage C/T							$ 2.20			
Profit C/T							$ 2.00			
GRAND TOTAL C/T DELIVERED							$18.71			

TABLE 5-6

EQUIPMENT EXPENSE SHEET FOR HANDLING 29,580 TONS/YEAR
OF WHOLE TREE CHIPS AT THE BOILER SITE

	Price	Avg. Annual Fixed Costs	Average Annual Maint./Yr	Avg.Fuel Cost/Yr	Labor Cost/Yr	Approximate Fuel Cost Per Ton	Total Cost	Power	Recommended Economic Life (Yrs)	Characteristics
BOILER SITE EQUIP.										
1 Truck Dump	$ 50,000	$ 16,000	$ 5,450	$ 3,830	$ 10,000	$0.13	$ 35,280	50 hp elec.	5	Cost includes hydraulic lift & foundations labor, 25-30 yr. oper. life 50 tons capacity
1 Hog	30,000	9,600	3,270	11,930		0.40	24,800	400 hp		
1 live bottom hopper	70,000	22,400	7,630	4,600	5,000	0.16	39,630	30 hp elec.	5	3 tons/minute 15-20 yr. oper. life
1 bulldozer	85,000	27,200	9,265	15,600	21,360	0.53	73,425	200 hp	5	10 yr. oper. life
1 metal detector	5,000	1,600	545	300	1,260	0.01	3,705	Approx. 1 kW	5	25 yr. oper. life
1 conveyor to storage	9,000	2,880	981	3,060	2,260	0.10	9,181	20 hp elec.	5	50' long/3 tons/min. 5 yr. oper. life
1 disc screen	13,000	4,160	1,417	1,530	3,270	0.05	10,377	10 hp elec.	5	3 tons/minute 5-10 yr. oper. life
Total	$262,000	$ 83,840	$28,558	$ 40,850	$ 43,150		$196,398			
Cost/Ton							$6.64			

TABLE 5-7

EQUIPMENT EXPENSE SHEET FOR HARVESTING AND TRANSPORTING 17,500 TONS/YEAR OF WHOLE TREE CHIPS FROM FIELD TO PILE (LONG RUN - 70-mile round-trip)

	Price	Avg. Annual Fixed Costs	Average Annual Maint./Yr	Avg.Fuel Cost/Yr	Labor Cost/Yr	Approximate Fuel Cost Per Ton	Total Cost	Power	Recommended Economic Life (Yrs)	Characteristics
HARVESTING EQUIPMENT										
1 Morbark SuperBeaver whole tree chipper	$ 42,500	$13,600	$ 4,632	$ 28,490	$ 19,848	$1.63	$ 66,570	350 hp	5	15" max. tree diameter, 100-150 tons/shift 7-10 yr. oper. life
2 feller bunchers	40,000	12,833	4,360	3,419	18,680	0.19	39,342	42 hp ea.	5	13" max. tree dia., quickly lightwt. 300 tons/shift 15-20 yr. oper.life
2 chainsaws	600	96	33	407	140	0.02	676	25 hp ea.	1	
1 grapple skidder	67,500	21,741	7,377	6,512	31,523	0.37	67,153	80 hp	4	300 tons/shift, 5-10 yr. oper. life
1 maintenance and fuel truck	15,000	4,831	1,639	4,477	7,005	0.26	17,952	55 hp	5	12 yr. oper. life
1 knife grinder	6,000	1,932	656	814	2,802	0.05	6,204	10 hp	4	25 yr. oper. life, replace grinding stone
Sub-Total	$171,300	$ 55,033	$18,697	$ 44,119	$ 79,998		$197,847			
Cost/Ton		$3.14	$1.07	$2.52	$4.57	$2.52	$11.31			
TRANSPORTATION										
2 chip trailers	$ 40,000	$ 13,000	$ 4,000	-----	-----	----	$ 17,000	0	4	Standard floor 27,000 tons/year; 54,000 lb payload, 7-9 yr. oper. life
1 tractor truck	75,000	18,500	8,500	8,485	20,000	0.48	55,485	350 hp	5	10 yr. oper. life
Sub-Total	$115,000	$ 31,500	$12,500	$ 8,485	$ 20,000	$0.48	$ 72,485			
Cost/Ton	$6.57	$1.80	$0.71	$0.48	$1.14	$0.48	$4.14			
TOTAL COSTS	$286,300	$ 86,583	$ 31,197	$52,604	$100,000		$270,138			
Total Operation C/T		$ 4.94	$1.78	$3.00	$5.71	$3.00	$15.45			
Stumpage C/T							$2.20			
Profit C/T							$2.00			
GRAND TOTAL C/T DELIVERED							$19.65			

TABLE 5-8

EQUIPMENT EXPENSE SHEET FOR HANDLING 17,500 TONS/YEAR
OF WHOLE TREE CHIPS AT THE BOILER SITE (SHORT RUN - 20-mile round-trip)

	Price	Avg. Annual Fixed Costs	Average Annual Maint./Yr	Avg.Fuel Cost/Yr	Labor Cost/Yr	Approximate Fuel Cost Per Ton	Total Cost	Power	Recommended Economic Life (Yrs)	Characteristics
BOILER SITE EQUIP.										
1 Truck Dump	$ 50,000	$ 16,000	$ 5,450	$ 3,830	$ 10,000	$0.22	$ 35,280	50 hp elec.	5	Cost includes hydraulic lift & foundations labor, 25-30 yr. oper. life 50 tons capacity
1 Hog	30,000	9,600	3,270	11,930		0.68	24,800	400 hp	5	
1 live bottom hopper	70,000	22,400	7,630	4,600	5,000	0.26	39,630	30 hp elec.	5	3 tons/minute 15-20 yr. oper. life
1 bulldozer	85,000	27,200	9,265	15,600	21,360	0.89	73,425	200 hp	5	10 yr. oper. life
1 metal detector	5,000	1,600	545	300	1,260	0.02	3,705	Approx. 1 kW	5	25 yr. oper. life
1 conveyor to storage	9,000	2,880	981	3,060	2,260	0.18	9,181	20 hp elec.	5	50' long/3 tons/min. 5 yr. oper. life
1 disc screen	13,000	4,160	1,417	1,530	3,270	0.09	10,377	10 hp elec.	5	3 tons/minute 5-10 yr. oper. life
Total	$262,000	$ 83,840	$28,558	$ 40,850	$ 43,150		$196,398			
Cost/Ton							$ 11.22			

The cost of whole tree chipping must include a tree cost (stumpage fee) to compensate for the timber or other value of the trees being chipped. This cost averages about $2.20/ton in the area of the three AAPs. Also, a profit of $2.00/ton is required.

The cost of handling whole tree chips and similar wood fuel at the fuel pile (boiler site) has been calculated herein. However, as stated in Chapter 1, this information is for reference purposes only. Almost all of the wood fuel handling equipment is separate from the required coal handling equipment, the cost of which should be calculated using Government criteria.

Whole tree chips arrive at the fuel pile site in vans usually carrying 23 tons of fuelwood. Even when occasional smaller loads are received there must be the capability of handling 23 ton loads.

Fuel handling equipment at the site of the fuel pile consists of:

Truck dump
Hog (fuel pulverizer)
Live botton hopper
Bulldozer
Metal detector
Conveyor
Disc screen

The truck dump selected herein permits rapid unloading of the chip vans without the added cost of live bottom trailers and without disconnecting the trailers. There are two dump types; one which lifts both tractor truck and chip van, and one which lifts only the chip van. The latter operation is more time consuming as the chip van must be disconnected from the tractor truck and the tractor truck must be driven away from the truck dump. After the truck dump is elevated, the chips are removed from the chip van by gravity through the rear doors.

The live bottom hopper receives the chips from the chip van on the elevated truck dump. The live bottom moves the chips to a conveyor. The conveyor transports the chips to the storage pile or container. A metal detector or magnetic separator is used to facilitate removal of any entrapped metal and a disc screen removes any larger than desired pieces of wood which are reduced in size by the hog. Costs of a set of typical wood fuel handling equipment at the pile is shown in Table 5-3.

The costs of whole tree chipping from on-site mature forest such as the woodlands on Milan AAP will benefit from the shorter transportation distances (see Table 5-4 versus Table 5-5).

5-1 IMPACT OF SCALE

The maximum scale of whole tree chipping operations chosen herein to estimate costs is 44,000 tons/year (Table 5-2). This capacity provides some reserve throughput to meet the requirements of KAAP (36,000 tons/year). The impact of scale of throughput on overall cost is easily seen. To chip up to 44,000 tons/year, one operator each is needed for the chipper, small feller-buncher, large feller-buncher, grapple-skidder and logger-forwarder. A single bulldozer operator is needed at the fuel pile (Table 5-2). This man would also operate the truck dump and conveyor system. If throughput was reduced to suit the wood fuel needs of IAAP (17,500 tons/year), it is likely that total manpower requirements on-site would only be reduced by two persons, a semi-trailer driver and a logger-forwarder driver. The impact on equipment would be to eliminate a tractor-truck, two semi-trailers and a logger-forwarder and to reduce the capacity of some of the other types of equipment. However, equipment is sized by tree diameter as well as throughput, so the cost reduction is only modest. Similarly, a single truck dump will be adequate for all capacities from 17,500 tons/year to over 100,000 tons/year, so no savings are possible here. A smaller hog could be used but total equipment costs could probably not be reduced in proportion to reduction in throughput.

5-2 CALCULATION OF TRANSPORTATION REQUIREMENTS

For the on-site whole tree chipping of existing AAP forest (possible only at MAAP), it was initially assumed that two tractors and three semitrailers (chip vans) of 23 ton capacity could handle the transportation requirements. This assumption was based on a 20 mile round trip distance, average speed of 30 mph, six minutes to dump trailers and four minutes to exchange empty trailers for loaded ones. Because the on-road time is 20/30 of an hour (40 minutes), the cycle time (total time) is 40 + 6 + 4 = 50 minutes. There are 600 minutes in a 10 hour day, so 600/50 = 12 trips could theoretically be made. However, there is the problem of accommodating lunch hours for the drivers and truck dump operators and ensuring that the driver of the last load of the day can make a round trip before quitting time. Also, delays on the road can occur. Theoretically, only 29,580/200 = 148 tons/day or 148/23 = 6.43 loads/day are needed so one truck is quite sufficient.

At 148 tons per 10-hour day, the van loading rate is 14.8 tons/hour and with 23 ton van loads, a load takes 1.554 hours or 93 minutes. Thus a truck can leave with a full van and return with an empty one in 50 minutes followed by 43 minutes waiting time. Therefore, the van loading rate controls the operation and the one truck plus two vans is the optimum equipment mix.

For the 70 mile round trip necessitated by off-site chipping, the average speed is 43 mph which means that road time is (70/43) = 98 minutes plus 10 minutes turnaround time for a total cycle time of 108 minutes. The van filling time is still 93 minutes so truck cycle time limits the operation. One truck can only make a maximum of 600/108 = 5.55 = five trips per day whereas 6.43 trips are needed. Thus two trucks are required. If a work day begins with empty vans at the chipping site, a truck cannot leave for 93 minutes until one van is filled. This truck cannot return for 108 minutes during which time one additional van and part of another have been filled. This scenario requires three vans and very tight scheduling between the two trucks and three vans. To maintain production some partial loads would have to be carried, which is uneconomical. Also, there is little excess capacity for good days when the chipping rate is above average. The best solution is to buy a fourth van for $20,000 so as not to tie up $338,950 worth of harvesting equipment (Table 5-5).

Similar calculations were made for the other two whole tree chipping cases in this study. All of the off-site whole tree chip transportation costs apply to slash chip transportation costs as well.

5-3 WHOLE TREE CHIP COSTS AT KANSAS AAP

The amount of green wood chips needed to meet MSR central boiler requirements at KAAP was shown to be 36,000 tons/year in Section 2-1. This amount of fuelwood cannot be produced annually on-site because of the limited existing forest (Section 2-2 d.). However, it is possible that off-site forests could produce this much wood. Data from the Kansas Utilization Forester indicates that 80,000 tons/year of trees are harvested each year. Because 36,000 tons/year of this production are required at KAAP, there would be enough timber from this source to satisfy the whole tree chip requirements.

As shown in Table 5-2, the delivered cost (harvesting cost plus transportation cost) of off-site chips at KAAP is $17.90/ton. Because three times as much wood as coal is required for fuel, the equivalent price of coal would have to be (3)($17.90/ton) = <u>$53.27/ton</u> whereas coal is available at $42/ton.

From Table 5-3, the cost of handling the wood fuel at the boiler site is $5.45/ton. There are no equivalent costs for coal handling available for comparison with this wood handling cost.

At 24 MBTU/ton for coal, 12,000 tons/year and 80% boiler efficiency, the proposed central steam plant must deliver (24)(12,000)(.8) = 230,400 MBTU. The cost of wood chip fuel is (36,000 tons/year)($17.90/ton) = $644,400. Thus the unit cost of steam energy from wood chips is ($644,400)/(230,400 MBTU) = <u>$2.78/MBTU steam</u>.

5-4 WHOLE TREE CHIP COST AT MILAN AAP

Milan AAP has two sources for whole tree chips (on-site and off-site). There are 7,000 acres of on-site land already in an existing forest. Because 29,580 tons/year of wood chips are required, the annual yield from these acres is only 4.23 tons/acre, which is well within existing norms for new growth in mature forests in the southeast. Alternatively, the area adjacent to the plant is heavily wooded and only four percent of the timber being cut within a 50 mile radius would provide an adequate supply of wood chips (Section 3-2 a.).

The economic differences between the two whole tree chip supply options at MAAP relate only to the transportation distances (70 mile round trips versus 20 mile round trips). The longer round trip loads require more hauling equipment and a larger expenditure of motor fuel. For both on-site and off-site operations, the stumpage costs ($2.20/ton) and profit ($2.00/ton) are the same as is the cost of harvesting the wood chips ($10.72/ton).

a. On-Site Whole Tree Chip Costs. The on-site whole tree chip costs at Milan AAP are given in Table 5-4 as $17.24/ton. Because three tons of wood are required to replace one ton of coal, the equivalent cost of coal would be (3)($17.24/ton) = $51.72/ton. However, coal is available delivered to MAAP at $44.67/ton.

From Table 5-6, the cost of handling the wood chips at the boiler site is $6.64/ton. There are no equivalent costs for coal handling available for comparison with this wood handling cost.

Based on 24 MBTU/ton coal, 9,860 tons/year coal usage and 80% boiler efficiency, the annual steam requirements at the MAAP central boiler plant are (9,860)(24 MBTU)(.80) = 189,312 MBTU. Using 29,580 tons of on-site wood chips to produce this steam, the annual cost is (29,580)($17.24) = $509,959. Thus the unit cost of steam would be: ($509,959)/(189,312) = $2.69/MBTU Steam.

b. Off-Site Whole Tree Chip Costs. The off-site whole tree chip costs at MAAP are given in Table 5-5 to be $18.71/ton. Because three tons of wood are required to replace one ton of coal, the equivalent cost of coal would be (3)($18.71/ton) = $56.13/ton. However, coal is available at MAAP at $44.67/ton.

As was previously shown in Table 5-6, the cost of handling the wood chips at the boiler site is $6.64/ton.

From Section 5-4 a., the annual steam requirements from the central boiler plant are 189,312 MBTU. Using 29,580 tons of off-site

wood chips at $18.71/ton, the cost of wood fuel to produce this steam is (29,580)($18.71) = $553,442. Thus the unit cost of steam would be ($553,442)/(189,312) = $2.92/MBTU Steam.

5-5 WHOLE TREE CHIP COSTS AT INDIANA AAP

The amount of green wood fuel needed at Indiana AAP was shown in Chapter 4 to be based on one million gallons of fuel oil annual usage. The energy content of 10^6 gallons of fuel oil is 140,000 MBTU. One ton of bitumiuous coal contains 24 MBTU. Thus 140,000 MBTU/24 MBTU = 5,833 tons of coal required annually. With 3 tons of green wood replacing one ton of coal, annual wood fuel requirements = (3)(5,883) = 17,500 tons/year. The annual cost of the required wood fuel for the proposed central boiler plant is (17,500 tons/year)($19.65/ton) = $343,875. At 80% boiler efficiency, the 140,000 MBTU of oil fuel used at IAAP produced 112,000 MBTU of steam energy. Therefore, the unit cost of steam would be ($343,875)/(112,000 MBTU) = $3.07/MBTU Steam. This fuelwood production rate is so much smaller than those of KAAP and MAAP that a different equipment mix is needed. The new equipment mix is shown in Tables 5-7 and 5-8. There is not enough standing timber at IAAP to permit on-site chipping (Section 4-1 a.). However there is adequate off-site timber.

From Table 5-7, the off-site whole tree chip costs at IAAP are $19.65/ton. Because three tons of coal are required to replace one ton of coal, the equivalent cost of coal would be (3)($19.65/ton) = $58.95/ton, whereas coal is available at IAAP for $49/ton.

From Table 5-8, the cost of handling the wood chips at the boiler fuel site is $11.22/ton. There are no equivalent costs for coal handling available for comparison with this wood handling cost.

CHAPTER 6

FOREST RESIDUE

During logging operations the limbs and that upper portion of the tree trunk below desired size, usually 10" in diameter, are cut from the sawlog before it is removed from the forest. This residue is referred to as slash and is generally left in the forest or tree stand to rot. Where these operations are easily accessible, local residents salvage a portion of the slash for residential firewood. In some cases, appropriate parts of the slash are salvaged by commercial firewood vendors.

This forest residue, which is equal to 80% of the weight of the sawlog removed (Chapter 7), provides an abundant potential source of fuelwood. There are two scenarios for retreiving this forest residue, one as a combined operation with the logging operation, the other as a separate operation.

Like whole tree chipping, either method of collecting and chipping forest residue requires equipment, labor and transportation. The size of the chipper must be able to take at least the 10" diameter top portion of the trunk left by the logging operation. The number of vans used to receive the chips must be consistent with the throughput of chippers used and the tonnage to be delivered to the fuel pile daily.

There appears to be little significant advantage between the two slash harvesting scenarios. If combined with the logging operation, it is assumed that the chipping of the forest residues will take place simultaneous with the removal of limbs and tops from the sawlogs. Thus additional manpower and equipment will be required compared to normal logging. Also chippers, vans and tractor trucks are required. The same manpower and equipment are required if the collection of forest residue is separate from the logging operation or occurs at a later time. However, the sawlog cutting operation may be selective, leaving immature trees standing, thus making access more difficult. Also, the amount of slash available for chipping could be sparse. This increases slash handling distances and thus costs. Cost estimates assume that enough logging occurs to provide enough slash to keep equipment busy. No actual cost data are available on this point.

The equipment required is:

chipper
grapple-skidder
forwarder
maintenance and fuel truck

knife grinder
chip trailer (van)
tractor truck (semi-tractor)
chainsaw

To determine the costs of collecting and chipping forest residue, it is necessary to determine the cost of appropriately sized harvesting equipment and the quantity needed to meet daily fuelwood demands. Only 200 operational days out of a maximum of 250 (five days per week for 50 weeks) should be used in the calculations to allow for bad weather conditions at all three AAP sites. However, 10-hour days will be used to permit working 2,000 hours/year.

As may be seen from the preceding paragraphs and a review of Chapter 5, the equipment and operating conditions for harvesting and transporting slash chips are essentially identical with those for whole tree chips. This is especially true for transportation and boiler site fuel handling. The differences between harvesting slash chips and whole tree chips are minor. Although most slash is less than 10" in diameter, short (uneconomically sized) sawlogs, diseased trees and undersirable type trees cut down and left during logging are also encountered. To chip this larger timber, a 20" diameter chipper is needed. Also, the throughput of slash chips (the same for each AAP as for whole tree chips), dictates use of high-rate chippers that typically are sized for 20" diameter logs. Therefore, the chippers should be the same as those selected for whole tree chipping.

Generally, the other major items of harvesting equipment will be the same as those chosen for whole tree chipping. The feller-buncher will be doing less felling when handling slash than whole trees but will need to do more bunching to get the same weight of wood with smaller pieces of timber. Basically, the harvesting equipment will have to travel more and work harder to process the same amount of wood chips as is obtained from whole tree chipping, wherein the weight of wood per acre is at least twice as great as is the case when only forest residue is chipped. This extra machine effort causes more fuel use and higher maintenance costs than is the case with whole tree chipping. However, whole tree chips cost an average of $2.20/ton extra because of a stumpage charge that is not usually required when slash is chipped.

It is the opinion of the UAH team that the extra cost for machine harvesting of forest residue is offset by the fact that this slash is not assessed the stumpage cost required for whole tree chipping. Therefore, all total costs calculated for whole tree chipping in Tables 5-1 through 5-8 should apply equally to chips obtained from forest residue.

6-1 FOREST RESIDUE COSTS AT KANSAS AAP

As indicated in Chapter 6, the cost of wood chips produced from off-site slash at KAAP should be the same as for the off-site whole tree chips cost presented in Section 5-3. Therefore, the appropriate costs are:

Delivered cost of chips	=	$17.90/ton
Equivalent cost of coal	= (3)($17.90/ton) =	$53.27/ton
Actual cost of delivered coal	=	$42.00/ton
Cost of energy from chips	=	$2.78/MBTU Steam

The cost of handling the chips at the KAAP boiler site was calculated for reference purposes only. This cost is $5.46/ton (Table 5-3).

6-2 FOREST RESIDUE COSTS AT MILAN AAP

The on-site forest at MAAP is only large enough to meet fuelwood requirements for MSR if the whole trees are chipped (Section 5-4). Therefore the forest residue must be obtained off-site in order to be the primary source of fuel. As shown in Table 7.2, the unused mill residue in the vicinity of MAAP is 269,825 tons/year. In Chapter 7, it is shown that the slash produced is almost twice the weight of the total mill residue. Thus at least 500,000 tons/year of slash are available near MAAP. As explained earlier in this chapter, there is no appreciable difference in cost between off-site whole tree chips and off-site chips from forest residue. Therefore, the cost of off-site forest residue fuel for MAAP can be taken from Section 5-4 b. as follows:

Cost of off-site forest residue fuel	=	$18.71/ton
Equivalent cost of coal	= (3)($18.71/ton) =	$56.13/ton
Actual cost of delivered coal	=	$44.67/ton
Cost of energy	=	$2.92/MBTU Steam
Cost of boiler site chip handling	=	$ 6.64/ton

6-3 FOREST RESIDUE COSTS AT INDIANA AAP

The on-site forest at IAAP is inadequate to produce enough residue to be the primary fuelwood supply for MSR steam requirements (Section 4-3 a.). However, adequate off-site forest residue exists for this purpose (Section 4-3). As stated earlier in this chapter, the whole tree chip cost is believed to be the same as the forest residue cost (see Section 5-5).

Cost of off-site residue	=		$19.65/ton
Equivalent cost of coal	= (3)($19.65/ton) =		$58.95/ton
Actual delivered cost of coal	=		$49.00/ton
Energy cost	=		$3.07/MBTU Steam

The cost of boiler site chip handling calculated for reference purposes only is $11.22/ton (Table 5-8).

CHAPTER 7

MILL RESIDUE

Mill residue is defined as the residue from cutting sawlogs into dimensioned lumber, or cutting or otherwise forming dimensioned lumber to form products such as pallets, boxes or furniture. The residue from sawmills cutting green wood is shown in Table 7-1.

TABLE 7-1

GREEN WASTE WOOD PER 1,000 BOARD FEET (LBS)

Data Source	Slash	Sawdust & Bark	Pieces	Total Mill Waste
Leonard Gould	15,000	-----	3,165	-----
Peter Koch	-----	2,406	5,041	7,450
TVA	-----	2,800	2,340	5,140
UAH (W.W. King)	14,400	4,680	3,780	8,460

For this study 4,680 lbs. of sawdust and bark and 3,780 lbs. of pieces are used. Pieces are reduced to chips where there is a market. Generally, clean chips, (without bark) are sold to paper or fiberboard processing plants at $16 per ton. Sawdust is sold for a variety of purposes where a market exists. Otherwise it is piled in open storage. The Doyle board foot scale used by W.W. King (Reference 8) assumes that 18,000 lbs. (nine tons) of sawlogs are cut for each 1,000 board feet (mmbf). The actual board feet produced under the Doyle Rule vary with log diameter and usually exceed the nominal quantity of 1,000 board feet per 18,000 lbs of sawlogs.

Prior to current existing restraints, sawdust was burned in teepees at the sawmill site. Since burning restrictions have been imposed it is piled in open storage if the mill has not made arrangements to use it as a fuel. Only larger sawmills have seen fit to use the sawdust as an on-site fuel; at smaller sawmills sawdust is a nuisance.

Most larger sawmills generate about 20 tons or more of sawdust and bark each operating day. Depending on the individual operation, the mill residue may or may not contain bark. Since the sawdust and bark is a nuisance, it can be purchased for fuel at low prices. The price needs only to be high enough to amortize the cost of the equipment necessary for collecting and transporting the sawdust, usually only two chip vans and a tractor truck. Most sawmills own one or more tractor trucks with associated flat bed trailers. This equipment is primarily used to transport logs and finished lumber. Also, one or more van trailers are kept on hand to carry away sawdust, bark and sometimes clean wood chips. It appears that most sawmill operators can afford to transport their sawdust, bark and chips for 50 to 100 miles for $0.08/ton-mile. In contrast, when the cost of making such trips with dedicated equipment was calculated for transporting whole tree chips off-site, the cost was found to be at least $0.10/ton-mile. Apparently, the sawmill operators have trucks and trailers bought primarily for hauling logs and lumber. Because this equipment is not utilized 100% for this purpose, the operators are willing to haul sawdust and bark for a low price. Another factor could be that the equipment used is not kept in first class shape because of the short haul distances.

It appears that it would not be cost-effective for trucks owned and operated by the AAPs to collect sawmill waste for fuel. Rather, the sawmill operators should be encouraged to continue hauling their waste to the buyer.

Within a 50 mile radius area, the average trip length is approximately 35 miles. Many sawmill operators are willing to transport sawmill waste over this distance for $0.08/ton-mile ($2.80/ton). The trailers used for this operation usually carry about 23 tons of sawdust and bark.

Once the sawmill waste is delivered to the AAP, an additional cost of $5.46/ton to $11.12/ton is needed to unload this material and place it in the storage pile and feed hopper. This is described as the boiler-site handling cost. The major equipment items are the truck dump, live bottom hopper, bulldozer (front loader), metal detector, conveyor, hog and disc screen. The same equipment would be used to handle whole tree chips, chips from slash and chips from energy plantations (see Chapter 5).

The boiler-site biomass fuel handling costs are not included when comparing the cost of coal to that of biomass fuel because no equivalent coal handling costs are available. However, the biomass fuel handling cost are presented here for reference purposes.

7-1 SAWMILL RESIDUE COSTS AT KANSAS AAP

To determine the availability and cost of sawmill waste for boiler fuel at the KAAP, the UAH team depended on both communication with local wood supply experts and field trips to operating sawmills.

As shown earlier in this Chapter, the production of 1,000 board feet of lumber generates more than four tons of mill waste. 40 million board feet (Doyle scale) of lumber produced annually in Kansas generate over 160,000 tons of mill residue or waste. The Kansas Utilization Forester estimated in February 1981 that 20,000 tons of mill residue is generated annually within a 50 mile radius of the Kansas AAP. In October 1982, the Area Extension Forester and the Kansas Utilization Forester estimated that 11,200 tons of sawmill residue and 7,000 of pallet assembly residue were available within the same area. It should be noted that this was all chippable waste which generally has a higher value ($15 to $18 per ton) than sawdust and bark. However, the amount of sawdust and bark normally produced at a sawmill is somewhat greater than the chippable waste and would be 22,533 tons/year, based on the proportions of Table 7-1.

Three sawmills within 25 miles of the AAP were visited in October 1982:

Midwest Forest Products, Independence, KS
Hardwood Products, St. Paul, KS
Shoenfeld Brothers, St. Paul, KS

These three mills each produce 3,000 tons/year of mill residue. There are five additional mills within the 25 mile radius of the AAP each producing an estimated 3,000 tons/year of mill residue:

Wilson Walnut Company, Parsons, KS
Messenger Lumber Company, Pittsburg, KS
Kenzal Hare, Independence, KS
LaRue Sawmill, Erie, KS
Konnech Brothers Sawmill, Oswego, KS

The estimated amount of sawmill residue (sawdust and bark) available for fuel at KAAP is 22,523 tons/year (Gould) and 24,000 tons/year (UAH team). Thus the UAH estimate of sawdust and bark from eight sawmills is (8)(3,000) = 24,000 tons/year whereas the amount based on the Kansas Forester's estimate was 22,523 tons/year (36,000 tons/year are required).

The cost of sawdust and bark in the vicinity of Kansas AAP was quoted at $5 to $7 per ton (1982 dollars). The costs of wood brokerage and transporting to the KAAP site are estimated to be $2.00/ton $2.80/ton respectively (see Chapter 7). Thus the delivered cost of sawmill waste to KAAP is $7/ton + $2.00/ton + $2.80/ton = <u>$11.80/ton.</u>

It is shown in Chapters 2 and 10 that it requires 3 tons of green wood fuel to equal the energy output of burning one ton of bituminous coal. Thus this coal would have to sell for (3)(11.80/ton) = $33.24/ton to equal the cost of sawmill waste fuel at KAAP. The delivered cost of coal at KAAP is $42/ton.

The energy output of the proposed KAAP central boiler house based on 12,000 tons/year of coal at 24 MBTU/ton and 80% boiler efficiency is (12,000 tons/year)(24 MBTU/ton)(.8) = 230,400 MBTU/year. Based on use of sawmill waste as fuel, the annual unit energy cost is: (36,000 tons)($22.80/ton)/230,400 MBTU Steam = $1.80/MBTU Steam. Unfortunately, there is not suffient sawdust and bark at KAAP to meet the MSR requirements.

7-2 SAWMILL RESIDUE COSTS AT MILAN AAP

As was the case at KAAP, the UAH team also conducted a field survey of sawmill waste at MAAP. This was particularly necessary because there were no recent specific estimates of unused sawdust and bark (potential boiler fuel) within a 50 mile radius of MAAP available from the local or state foresters as was the case in Kansas. However, the field survey produced evidence of adequate sawmill waste fuel and another fairly recent source of waste wood data was also obtained. The unused (avaliable) wood residue including mill residue from all sources in the 16 counties within economical transportation distance (50 miles from MAAP) was surveyed by the Land and Forest Resources Division of the Tennessee Valley Authority in 1979. The results of this survey are shown in Table 7-2. From this table, the unused sawmill waste of primary interest (sawdust and bark) totaled 212,750 tons/year.

TABLE 7-2

UNUSED WOOD RESIDUE (Initial Condition)

(TONS/YEAR)

16 COUNTIES AROUND MILAN AAP

County	Bark	Chippable	Shavings	Fine Sawdust	Total
Benton	290	607	115	10,656	11,668
Carroll	0	0	0	6,148	6,148
Chester	3,468	0	0	8,958	12,426
Decatur	2,604	796	0	17,304	20,704
Gibson	0	772	170	36	978
Hardeman	9,277	10,926	887	18,180	39,270
Haywood & Lauderdale	7,335	1,638	62	15,766	24,801
Henderson	1,357	2,163	1,959	8,860	14,339
Henry	1,874	1,101	1,611	8,794	13,380
Lake & Obion	6,935	29	446	11,153	18,563
Madison	4,581	17,418	3,600	9,880	35,479
McNairy	6,547	3,111	577	14,731	24,966
Perry	9,205	8,435	0	17,857	35,596
Weakly	3,808	535	18	7,146	11,507
16 counties	57,281	47,630	9,445	155,469	269,825

Source: Appendix D-1 and D-5, Residues produced in Tennessee Valley counties and non-Tennessee Valley counties, by county and species group, 1979; Production and Use of Industrial Wood and Bark in the Tennessee Valley, Division of Land & Forest Resources, Tennessee Valley Authority; Technical Note 845, April 1981.

Table 7-2 can also be used to calculate the tonnage of whole trees harvested because sawlogs and slash totaling 32,400 lbs produce 8,460 lbs of total sawmill residue (Chapter 7). Thus the weight of whole trees harvested is approximately four times the weight of sawmill residue if the Doyle scale is used.

There are about 20 sizeable sawmill and wood products firms within economical transportation distance of MAAP. In most cases, these operations sell their chippable residue to area paper or fiber-board mills for processing or fuel. Some of the sawdust is sold to Kentucky tobacco farmers and area turkey producers. However, a survey of 12 of the 20 wood fuel sources conducted in November 1982 as a part of this study identified sources for 168 tons of sawdust and bark per day (42,000 tons/year, see Table 7-3) which exceeds MAAP peacetime wood fueling requirements of 29,980 tons/year. Of course, the TVA fuel estimate is about seven times this requirement. Considering the depressed market for lumber in 1982, it is reasonable to assume that an adequate supply of boiler fuel will be available in the future because the amount of potential MAAP boiler fuel currently available is already adequate.

The MAAP would have to compete for the committed mill residue supply, but the shorter hauling distance would be very attractive to the mills contacted during the 1982 survey. The utilization of mill residue is the most cost-effective of the biomass fuel options.

The economics of the wood waste supply situation around Milan is complex. There is inadequate steady demand for sawdust and bark. Clean (bark free) waste can be chipped and then shipped to wood fibre plants in Wickliffe, Kentucky and New Johnsonville, Tennessee at a delivered price of about $16/ton. These same buyers also use bark and sawdust as boiler fuel. The Kentucky plant buys 600 tons of wood fuel per day. However, the price is low, about $6.50/ton plus a mileage allowance of a maximum of $2.50/ton. A small amount of bark is ground up and "cured" in piles for about a year so that it can be sold to nurseries for plant mulch. Large sawmill operators such as Replogle at Henry, Tennessee use some of their waste to fire boilers for heat in wood kilns.

Overall, the total market for wood waste fuel is inadequate for the supply, even though the economic recession has depressed the production of wood products. The Huey Brothers mill in Obion has on hand a two year (10,000 ton) accumulation of sawdust. The UAH survey indicated that there were 117 to 168 tons/day of waste wood fuel uncommitted in the Milan area. Price is hard to establish as most of this material is not being sold. However, several operators expressed strong interest at a delivered price of $9 to $10/ton. There is approximately an equal quantity of waste wood fuel currently being

TABLE 7-3

MILL RESIDUE SURVEY

	AVAILABLE		COMMITTED		
FIRM	QUANTITY	PRICE	QUANTITY	PRICE	COMMENTS
Menefe Bros. Troy			17 tons/day S & B 22 tons/day chips	$8-9/ton $6.50-6.75/ton*	Sells to Inland Container
Huey Bros. Obion	14 tons/day S & B	Not being sold - 1982	56 tons/day chips 60-80 tons/day		10,000 tons dust available (2 yr. accumulation)
Replogle** Henry			40 tons/day sawdust 20 tons/day sawdust chips***	$7.50/ton $18/ton	Sells bark mulch @ $635 a 88 cubic yard load - Memphis
Southern Star McKenzie	20-25 tons/day	Not being sold - 1982	20 tons/day chips	$16/ton	Interested in Milan potential - other inquiries
Shemaker McKenzie	30 tons/day slabs	$6.67/ton	15 tons/day sawdust 10 tons/day bark	$6/ton $6.50/cu.yd.	
K T & L Greenfield			10 tons/day S & B	$7.75/ton	Sells to Inland Container & Westvaco Cord
K & M Sharon	15 tons/day sawdust 20 tons/day bark				Sells to Celotex & Inland
Powell Brownsville			15 tons/day S & B	Sold & delivered 100 miles	Will sell (1983) to Milan AAP at $10/ton
Storey Troy	34 tons/day S & B				Not currently operating Data from Menefee
Jackson Mill (Menefee) Jackson	17 tons/day S & B 6 tons/day shavings			—	Information from Troy Mill
Dyer Fruit Box - Dyer					No quantities - all being sold in 1982
Milan Box Milan	12-15 tons/day	Not being sold landfill	1000 tons/year	$14/ton	Using internally in winter - selling in summer
TOTAL 75% of Total 70% of total	168 tons/day 126 tons/day 117 tons/day	12 Firms contacted 9 area Mills not contacted	***Sell dust to tobacco farmers - ran out in 1982	*$16/T delivered 100 miles **Use wood to fire boilers to dry wood	

Source: Survey by UAH personnel, November 1982

sold to Westvaco, Celotex and Inland Container. Assuming a mill site price of \$6.50/ton and an average travel distance of 35 miles to Milan and \$0.08/tonmile, a price of \$9.30/ton would be competitive. Wood suppliers could make twice as many trips to Milan as they could to Celotex, Inland or Westvaco because of the shorter distances involved. Therefore an MAAP fuel buyer should be able to compete for some of the committed local sawdust and bark supply as well as for the 42,000 tons/year of available (uncommitted) boiler fuel located by the UAH team.

CALCULATION OF TOTAL FUEL COST

Millsite Cost	\$6.50/ton
Transportation Cost	\$2.80/ton
Wood Brokerage Fee (optional)	\$2.00/ton
TOTAL COST	\$11.30/ton

It is shown in Chapters 2 and 10 that 3 times as much green wood is required to replace coal as boiler fuel. Thus this coal would have to cost (3)(\$11.30/ton) = \$33.90 whereas the delivered price of coal at MAAP is \$44.67/ton.

The energy output of the proposed MAAP boiler house based on 9,860 ton/year coal usage is (9,860 tons/year)(24 MBTU/ton)(0.8) = 189,312 MBTU/year. The annual fuel cost is (29,580 tons/year)(\$11.30/ton) = 334,254/year. Annual energy cost = (334,254)/(189,312 MBTU) = \$1.77/MBTU Steam.

The cost of boiler site fuel handling, calculated for reference purposes only, is the same as for wood chips and is \$6.64/ton (Table 5-6).

7-3 SAWMILL RESIDUE COSTS AT INDIANA AAP

The UAH team also conducted a field survey of sawmills within a 50 mile radius of IAAP as well as utilizing published resource data. These data indicate that the area timber production in 1971 was about 31 million board feet (31 mmbf). As shown in Table 7-1, the mill waste (sawdust and bark) produced from processing this much timber into lumber should be (31 mmbf)(4,680,000 lbs/mmbf)/2,000 lb/ton = 72,540 tons/year. This number is considered to be low because of the known growth of the sawmill industry in this area since 1971. The smallest Indiana sawmill (Fleenor) visited by the UAH team produced 10

tons of sawdust and bark per day (2,500 tons/year). Thus the 67 sawmills in the area could produce (67)(2,500) = 167,500 tons/year.

Data provided by Indiana State Forestry Commission identified the 67 sawmills and wood products industries in the eight Indiana counties surrounding the AAP. The State Utilization Forester (Mr. Don McGuire) listed 14 sawmills in the area which would be major potential suppliers of mill residue. Nine of the 14 were visited in December 1982 (see below).

C.H. Best & Sons, Floyd County
*Eugene Hackman, Jackson County
Jerry D. Hall, Jackson County
*Thomas Hall, jackson County
*Baxter Lumber Company, jefferson County
*Norman Foster, Jennings County
*Burton Lumber Company, Scott County
*DeHart pallett & Lumber Company, Scott County
*Fleenor Sawmill, Washington County
Housewoods, Inc., Washington County
King Lumber Company, Jefferson County
Clark Brothers Sawmill, Jefferson County
*Funk Lumber Company, Scott County
*Paul L. Wheeler, Washington County

Mills actually visited are indicated by an asterisk. The nine mills visited were producing an average of 20 tons of sawdust and bark per work day (five days/week) and most were selling and hauling the residue (and chips in some cases) to Willamette Paper Company at Hawesville, Kentucky. Hauling distances were from 90 to 140 miles. Each complained that the price paid for bark and sawdust (quoted as $7.90/ton in one case only) just about covered transportation cost. Each indicated an interest in hauling mill residue to Indiana AAP at the same price (or, hopefully a little more) due to the reduced distance, (not greater than 50 miles). The nine mills visited out of a recommended 14 would produce a total of 45,000 tons/year. It is reasonable to assume that the other five mills not visited would produce another 25,000 tons/year. Thus the total sawdust and bark produced in the area would be 70,000 tons/year (based on 14 <u>large</u> sawmills) and 167,500 tons/year (based on average output <u>of all</u> 67 sawmills in the area). However, only 17,500 tons/year are required to meet wood fuel needs for MSR operation of the IAAP central boiler plant.

CALCULATION OF TOTAL FUEL COST

Delivered Cost	$7.90/ton
Wood Brokerage Fee	$2.00/ton
TOTAL COST	$9.90/ton

Because 3 times as much green wood fuel as coal are required to produce an equal amount of steam energy, the cost of coal would have to fall to: (3)($9.90/ton) = $29.70/ton to be equivalent to mill waste fuel at IAAP. The delivered price of coal at IAAP is $49/ton.

The annual energy output of the proposed IAAP central boiler plant based on one million gallons of fuel oil and 80% boiler efficiency is: (140,000 BTU.gal)(10^6 gal)(0.8) = 112,000 MBTU Steam. The annual cost of wood fuel is (17,500 tons/year)($9.90/ton) = 173,250. The cost of energy is: 173,250/(112,000 MBTU Steam) = $1.55/MBTU Steam.

The coal available at IAAP costs $49/ton. The cost of the coal to replace the 17,500 tons of green wood is: ($49/ton)(17,500 tons)/3 = $285,833. The steam cost = ($285,833)/(112,000 MBTU) = $2.55/MBTU Steam.

The cost of handling the sawmill waste at the IAAP boiler site would be the same as for handling an equal quantity of wood chips and thus would be $11.22/ton (Table 5-8).

CHAPTER 8

FUELWOOD PLANTATIONS

8-1 GENERAL BACKGROUND

Fuelwood plantations (energy forests) have been studied and proposed as viable large-scale fuel sources for several years. Fuelwood plantations differ from tree farms planted to produce polewood, pulpwood or timber. This is true because unlike conventional tree farms, fuelwood plantations are designed with little concern for the diameter or height of trees at harvest time. Also, the specie of tree is relatively unimportant except that it be fast-growing, suited to the location and capable of coppicing (sprouting from a stump). The specie of tree is also unimportant from a BTU/lb content because most fast-growing trees have an oven-dry energy content of around 8,600 BTU/lb. Of course, the chosen species of trees must be reasonably disease-resistant. The problem of tree disease can be minimized by choosing three different species for a given plantation so that the impact of specie-peculiar diseases is reduced.

The usual procedure for designing and operating a fuelwood plantation is to determine how many BTUs of fuel to be burned at 80% boiler efficiency are needed. From a previously established BTU/acre table or tons/acre table, the spacing of trees per acre and the frequency of cutting can be chosen to determine the acres required. However, it is probably best to first consult another table or matrix that provides information on the tree-spacing/harvesting-cycle combination that provides the lowest total production cost per ton. The production cost consists of:

- o Growing costs (site preparation, weed control, seedlings, planting labor)
- o Land cost (loss of net annual revenue)
- o Harvesting, chipping and transportation costs

However, harvesting, chipping and transportation costs are basically independent of tree spacing within reasonable limits of annual output per acre. Therefore, to select an optimum plantation scheme, it is necessary to combine growing costs and land costs to form a matrix of total stumpage costs per ton. From this table, the harvest cycle time and tree spacing are chosen to provide the lowest stumpage cost ($/ton). Then the table on yield per acre can be used to calculate the required number of acres.

8-2 OPERATION OF THE PLANTATION

After the acreage requirements, harvesting cycles and tree spacing have been determined as detailed in Section 8-1, the land preparation begins. For example, if the total acreage was 5,000 and the harvesting cycles consisted of three five-year intervals (the 5+5+5 approach), a 1,000 acre plot would be prepared beginning as soon as possible. The land would be plowed and disced to kill grass and prepare the soil, assuming that the land had been in pasture or planted with a cover crop of grass. Then machine planting would take place followed by application of weed control powder. The weed control and discing would be repeated prior to the start of the second growing season. During the remaining three years, the trees would not normally require additional treatment unless there was a disease problem.

At the end of five years, the first plot would be ready to harvest using conventional wood harvesting equipment such as chainsaws, tractors and chippers. However, the chipping operation would be delayed up to six months after felling. This is to permit the cutdown trees to field dry to 20% moisture content from the 40% to 50% moisture content (total weight basis) that exists at cutting time. These data are based on actual experience in Northeast Kansas and include the effects of rain and snow on field drying. Field drying improves the combustion efficiency of the wood from 65% at 50% moisture to 80% at 20% moisture (see Chapter 10). Thus the amount of fuelwood needed to provide a given annual Btu requirement of boiler output is minimized.

The treatment of the other four equal-sized energy forest plots would be exactly the same as the first except that operations would begin on successive years. Thus at five years, the first fuelwood production would begin and it would be continuous from then on as other plots of trees matured.

After the first trees planted are cut down, they will "coppice" (sprout stems from the stumps). This eliminates the planting cost for the second and third generation of trees, although it may be necessary to thin out multiple stems for some species. The number of times that coppicing can be accomplished is somewhat indeterminate but it has been shown that three cuttings (two coppicings) produce good results. In the example shown, the first plot planted would be out of production at the end of 15 years. Then the stumps would be mechanically uprooted and disposed of so that planting could begin again. In some cases, it may be practical to chip the stumps for `dditional fuelwood. It may be seen that the fuelwood plantation can be a continuous source of wood forever, especially if there are periodic applications of fertilizer.

8-3 THE KANSAS AAP FUELWOOD PLANTATION

It was shown in Chapter 2 that the Kansas Army Ammunition Plant (KAAP) required 12,000 tons/year of coal to meet peacetime (MSR) steam requirements from the central boiler plant. In Chapter 10 it is stated that both as-received bituminous coal and wood chips having 20% moisture content can be burned in medium-sized boilers at 80% efficiency. Therefore, the annual BTU requirements from the field-dried fuelwood produced from the energy forest would be the same as for coal. This is (12,000 tons/year)(2,000 lbs/ton)(12,000 BTU/lb) which equals 288,000 MBTU/year. It is further stated in Chapter 2 that up to 9,000 acres of land could be made available at KAAP for a fuelwood plantation. It was assumed that the logistics of acquisition of a new central boiler plant are such that it will be ready to operate in five years. Thus a five year harvest cycle was chosen.

The basic reference for the energy plantation calculations in this section is the 1982 paper "An Economic Analysis of Energy Forest Plantations", by Naughton and Geyer, which is included in Appendix C. Mr. Naughton was contacted by the UAH team both in person and by mail to ensure proper usage of his data in this study. This paper is particularly valuable in that it facilitates the "least cost" approach to designing fuelwood plantations. Because Naughton's paper is in metric units, it is advantageous to convert to these units early in this exercise. Thus the reference may be reviewed with minimum difficulty.

9,000 acres/2.471 = 3,642 hectares

288,000 MBTU/(18.96 MBTU/ODMT) = 15,190 ODMT

Thus the minimum fuelwood output of the 3,642 hectare plantation is 15,190 Oven-Dry-Metric-Tons annually. Given a five year harvest cycle, the yield during harvesting for each equal-sized plot is (15,190)(5)/3,642 = 20.85 ODMT/hectare. From Table 8-1 below it can be seen that any tree spacing in excess of 1,400 trees/hectare will satisfy the requirement.

TABLE 8-1

YIELD IN DRY METRIC TONS PER HECTARE

	trees per hectare				
Age (n)	7,000	4,700	3,200	2,100	1,400
4	27.5	23.7	20.6	17.4	15.2
5	36.8	32.8	28.9	23.8	21.2
6	43.3	38.2	34.8	31.5	29.3

Table 8-1 is valid for one, two or three harvests from the same plot. The maximum average annual growth rate is 36.8/5 = 7.36 ODMT/hectare. This can be converted to actual (green) short tons/acre. Using the proper conversion factors and a 100% weight increase (50% moisture content) yields 6.56 green short tons per acre. This compares with an annual growth rate of three to five green short tons/acre for a normal forest.

It is next necessary to select the lowest cost tree density for the 5+5+5 planting cycle from Table 8-2.

TABLE 8-2

TOTAL STUMPAGE COSTS PER DRY METRIC TON, 3 CUTTING CYCLES

	trees per hectare				
Age	7,000	4,700	3,200	2,100	1,400
4+4+4	$48.85	$47.24	$47.23	$49.82	$52.55
5+5+5	41.76	39.39	39.18	42.65	44.79
6+6+6	40.22	38.59	37.34	37.19	37.05[1]

This cost is found to be $39.18/ODMT at 3,200 trees/hectare. Returning to Table 8-1, this option produces 28.9 ODMT/hectare. Therefore, the original 9,000 acre assumption can be reduced to 9,000 (20.85/28.9) = 6,493 acres = 2,628 hectare.

The stumpage cost from Table 8-2 was $39.18/ODMT. To this must be added the harvesting, chipping and transportation cost of $30.35/ODMT.

The boiler site handling cost, provided here for reference purposes only, would be $196,398 - $35,280 = $161,118/year from Table 5-3. The $35,280/year cost for the truck dump is eliminated by use of dump trucks.

TOTAL FUELWOOD COST

Stumpage Cost	$39.18/O.D.M.T.
Production and Transportation Cost	$30.35/O.D.M.T.
TOTAL	$69.53/O.D.M.T.

From a previous calculation, 15,190 ODMT annually were required. Thus the cost of energy is
(15,190 ODMT/year)($69.53/ODMT) = $1,056,161/year. For KAAP coal to cost as much as fuelwood, it would have to sell for $1,056,161/12,000 = $88.01/ton. However, the delivered price of KAAP coal is $42/ton. At 80% furnace efficiency, the annual steam energy output is (288,000 MBTU)(0.8) = 230,400 MBTU. Thus the cost to produce energy is ($1,056,161)/(230,400 MBTU) = $4.58/MBTU Steam.

It is useful to compare Naughton's land cost to actual costs at KAAP. This land is leased for grazing at $11.86/acre and row cropping at $68.90/acre. Thus the average lease revenue would be $40.38/acre. From Table 8-3, Naughton's cost was $17.20/ODMT.

TABLE 8-3

LAND COSTS PER DRY METRIC TON (5%)

	trees per hectare				
Age (n)	7,000	4,700	3,200	2,100	1,400
4	14.11	16.37	18.83	22.29	25.52
5	13.51	15.16	17.20	20.90	23.68
6	14.13	16.02	17.59	19.42	20.88

These costs are valid for any number of harvest cycles per plot because they represent simple annual land rent.

The previous calculations showed a production of 15,190 ODMT from 6,490 acres so land cost is:
(15,190 ODMT)($17.20/ODMT)/ 6,493 acres = $40.24/acre. This is close enough to $40.38 acre to use the original fuelwood energy cost calculations.

The boiler site handling cost was shown previously in this section to be $161,118/year. To get this cost per ton of fuelwood, it is necessary to convert 15,190 ODMT to short tons of wood containing 20% moisture. The conversion is: (15,190)(2,205/2,000)(1/.8) = 20,796 tons. Thus the boiler site handling cost per ton is $161,118/20,796 = $7.75/ton.

8-4 THE MILAN AAP FUELWOOD PLANTATION

It was shown in Chapter 3 that the Milan AAP central boiler coal requirement is 9,860 tons/year for MSR compared to a 12,000 tons/year for Kansas AAP given earlier in this chapter. It follows that the amount of oven dry metric tons of fuelwood needed for MAAP

would be reduced in proportion to the KAAP requirements: (15,190 ODMT/year)(9,860/12,000) = 12,481 ODMT/year. As shown earlier, this output would require (9,860/12,000)(6,493) = 5,335 acres and 13,221 acres are available at MAAP. The question arises as to the impact of this smaller fuelwood throughput on costs/ton. Communication with Gary Naughton revealed that his paper on energy forests provided costs based on a total forest size of 1,200 acres and a haul distance of 13 miles. His harvesting equipment was lightweight chippers, chain saws and trailers pulled by small farm tractors. Transportation to the boiler site was by dump truck. With this equipment mix, there is little potential for a change in harvesting costs when the total forest size is increased beyond 1,200 acres. Therefore, the cost/ODMT at MAAP would only be different from that at KAAP by the difference in land cost and the slightly higher cost for boiler site fuel handling that occurs if a smaller number of tons/year is handled by the same capacity equipment.

From data gathered at MAAP, the land lease costs for row crops and grazing in 1981 were $68.50/acre and $21.50/acre, respectively. Thus the average of these land rent costs is $45/acre. This is so close to the one used for Kansas AAP ($40.26/acre) that the optimum tree spacing and subsequent unit production and transportation costs from Table 8-2 should also be similar. However, a separate calculation for land rent is possible. The metric land rent costs from Table 8-3 were $17.20/ODMT. This would change in proportion to the increase in non-metric land costs ($45/acre vs. $40.26/acre by $17.20 (45 -40.26)/40.26 = $2.02/ODMT. This is added to the total stumpage cost from Table 8-2 of $39.18/ODMT to give $41.20/ODMT.

The boiler site handling cost from Table 5-6 ($196,398 - $35,280) = $161,118/year. Converting the annual wood fuel requirements to 80% moisture and English units:
(12,481 ODMT)(2,205/2,000)(1/.8) = 17,200 tons/year. Thus the boiler site handling cost per ton is ($161,118)/(17,200 tons) = $9.37/ton.

TOTAL MAAP FUELWOOD COSTS

Total Stumpage Cost	$41.20/O.D.M.T.
Production and Transportation Cost	$30.35/O.D.M.T.
TOTAL COST	$71.55/O.D.M.T.

This cost applies to the 12,481 ODMT/year previously calculated. Thus the cost of wood energy is
(12,481 ODMT/year)($71.55/ODMT) = $893,016/year. For the energy cost of the 9,860 tons of coal required annually to equal this cost, coal would have to sell for $893,016/9,860 tons = $90.57/ton. However,

coal is available at MAAP at \$44.67/ton. At 80% boiler efficiency, the annual steam energy output is (9,860 tons/year)(2,000 lb/year)(12,000 BTU/lb)(0.8)/10^6 = 189,312 MBTU/year. Thus the cost to produce energy is (893,016/year)/189,312 MBTU = $\underline{\text{\$4.72/MBTU Steam}}$.

8-5 THE INDIANA AAP FUELWOOD PLANTATION

It was shown in Chapter 4 that one million gallons of fuel or equivalent energy would be needed at the new IAAP central boiler plant. This amount of energy is: (10^6 gallons)(140,000 BTU/gal) = 140,000 MBTU/year. From previous calculations in this chapter, there are 18.96 MBTU/ODMT. Thus fuelwood required is (140,000 MBTU/year)(18.96 MBTU/ODMT) = 7,384 ODMT/year. From Table 8-1, the average annual yield/hectare is 28.9/5 = 5.78 ODMT/ha. The required total plantation area is:
7,384 ODMT/(5.78 ODMT/(5.78 ODMT/hectare) = 1,277.5 hectares = 3,156 acres. From Section 4-3 d., there are only 2,000 acres available for an energy forest. Thus this area would be inadequate for the purpose even if the planting density was increased to 7,000 trees/hectare (Table 8-1).

Another possibility would be to cut down the standing forest and replace it with an energy forest. This option is not practical because of the high value of the existing sawtimber and poor potential of producing low cost fuel from a fuelwood plantation. Therefore, the cost of the fuelwood plantation at IAAP was not calculated.

CHAPTER 9

AGRICULTURAL RESIDUE

There are several types of agricultural residue that are suitable for combustion in a medium size boiler. Within the areas surrounding the three AAPs surveyed herein, the primary residues are wheat straw, hay, corn stover and soybean stover. Stover is the portion of the plant remaining above ground after the edible portion (corn ears or soybean pods) have been harvested. There is some question as to whether or not hay should be included as an agricultural residue because it is a primary crop. However, wheat straw is often used in place of hay so both types of material were included in this study. Corn and soybean stover are farm byproducts with cash value both as animal feed and soil conditioners. Modern farming practice dictates that approximately 80% of straw or stover should be worked back into the soil to maintain tilth and protect against soil erosion.

It is possible to collect and bale both soybean and corn stover. This practice permits short term storage of the stover for animal feed. However, this practice is not widespread and only one instance of it was seen during over 1,000 miles of rural road travel near the three AAPs. In order to include this material as a viable AAP fuel, a collection, baling and storage infrastructure would have to be developed in advance of the biomass fuel requirements date at the AAPs. This is clearly not a realistic situation. Therefore, the agricultural biomass fuels given further consideration herein are hay and straw.

Hay and straw are similar in character. They are mostly cellulose and are baled at an average moisture content of 14% (Reference 9). However, the possibility of moisture gain between baling and use is such that it is assumed that the material will contain about 20% moisture when it is burned. At this moisture level, the net energy content will be about 6,000 BTU/lb (Reference 9) and it should be possible to burn this fuel at 77% boiler efficiency (coal burns at 80% efficiency). The hay or straw will replace the boiler coal requirement in the ratio of (12,000/6,000)(80/77) or 2.078 ton/ton. Allowance for 20% deterioration in storage increases this ratio to 2.6 ton/ton.

Some other differences between hay/straw and wood fuel cause added costs when using the former as fuel. The national trend in baling is toward the large, loose, round bales of about 1,500 lbs. each. These bales are more difficult to transport than wood waste so the transportation cost should be doubled compared to sawmill residue (2 x \$2.80/ton = \$5.60/ton). The waste wood fuels are more dense than

hay/straw bales and about 23 tons can be carried in a standard 45 foot semitrailer van compared to about half that tonnage with hay/straw. Actually no data are available on highway transportation of round bales of hay/straw because this is seldom done. Instead, rectangular bales are used for this purpose but these are more expensive and thus were not considered.

In order to compare hay/straw costs to those of wood fuel, consideration must be given to the added storage costs of hay/straw because of the low density of the material. Also, the hay/straw will deteriorate in open storage at a rate of about 20% per year (covered storage is impractical). Long-term open storage is dictated by the fact that, unlike wood fuel, hay/straw is only produced during about two months of the year. It is believed that the characteristics of hay/straw are such that the AAP on-site handling costs for this material should be twice those calculated for sawmill waste.

The high unit energy cost and problems associated with handling and storage of hay/straw appear to be universal within the U.S. A literature search has failed to find a single case where this material was used as the primary year-round fuel for a medium size boiler. The nearest case is a location in Southern California wherein cotton hulls are cost-competitive with NO. 2 heating oil.

9-1 AGRICULTURAL RESIDUE AT KANSAS AAP

Kansas is a wheat state and wheat is the principal crop in the vicinity of KAAP. Kansas produces about 300 million bushels of wheat, 200 million bushels of sorghum and 150 million bushels of corn annually. This crop production generates about 11 million tons of wheat straw and 11 million tons of stover from sorghum and corn annually (Reference 3). The costs for wheat straw range from $18 to $22 per ton for rectangular bales (Reference 4 and 5). Round bales cost slightly less ($19/ton).

Corn stover costs range from $13 per ton for loose crop harvest systems (unbaled) to $27 per ton for rectangular bales (Reference 5).

Straw is the largest and most economical residue in the vicinity of KAAP. To replace 12,000 tons/year of coal at 12,000 BTU/lb with wheat straw would require (12,000)(2.6) = 31,200 tons of straw (see Chapter 9). This much straw represents only 5.25% of the annual production within a 50 mile radius of KAAP. Most of this straw is in round bales at an average cost of $19/ton. As shown in Chapter 9, the transportation cost should be about $5.60/ton. Also, boiler-site handling cost is estimated to be twice that of wood fuel at KAAP (see Section 5-3) which is (2)($5.46/ton) = $10.92/ton.

CALCULATION OF AGRICULTURAL RESIDUE COST

Wheat Straw Cost	\$19.00/ton
Transportation Cost	\$ 5.60/ton
Delivered Cost of Fuel	\$24.60/ton

The boiler fuel input = (12,000 tons/year)(24 MBTU/ton) = 288,000 MBTU/year. At 80% boiler efficiency, the steam output is 230,400 MBTU/year. The cost of this steam is:

$$\frac{(31,200 \text{ tons})(\$24.60/\text{ton})}{(230,400 \text{ MBTU})} = \underline{\$3.23/\text{MBTU Steam}}$$

Because 2.6 tons of straw are required to replace one ton of coal, the equivalent price of coal would be (\$24.60)(2.6) = <u>\$63.96/ton</u> whereas the delivered price of coal at KAAP is \$42/ton.

9-2 AGRICULTURAL RESIDUE AT MILAN AAP

The farming around MAAP is mostly on small plots of land. In several hundred miles of travel on rural roads, the UAH team saw no evidence of baling of stover (corn or soybean). The only agricultural residue seen to have been collected was a few round bales, either wheat straw or hay. This material was located in cattle raising areas. From personnel at MAAP, it was learned that hay sells for about the same price as did wheat straw in Kansas. The amount of hay or straw required for boiler fuel would be 2.6 times the amount of coal needed at the central boiler house (2.6)(9,860 tons/year) = 25,636 tons/year. This is roughly 34,000 round bales. Because this amount of hay or straw is only produced twice per year, there would have to be about 14,000 bales in the fields after the autumn cutting. The UAH team saw only a few hundred bales during the field survey. There may have been considerably more rectangular bales in covered storage, but this material is too expensive to use as boiler fuel.

The 1982 Bulletin of Tennessee Agricultural Statistics gives no data on wheat straw production or production of hay by county. However, the average price of hay was \$46/ton, making it unacceptable as fuel.

The conclusion of this section is that the agricultural residue supply around MAAP is so inadequate for boiler fuel purposes that calculation of unit costs would be unrealistic.

9-3 AGRICULTURAL RESIDUE AT INDIANA AAP

Table 9-1 describes the potentially collectible agricultural residue in the vicinity of Indiana AAP.

It is seen that corn and soybeans represent major sources of collectible residues. However, these residues are seldom collected and baled. As stated earlier in this chapter, only one instance of such as operation was seen during all of the rural travel around the three AAPs. Thus the major potentially collectible residues available from Table 9-1 are 7,830 tons/year of wheat straw and 23,238 tons/year of hay. Thus approximately 31,000 tons/year of baled residue could be available. The central boiler house at IAAP would require one million gallons/year of heating oil (140,000 MBTU/year). The equivalent amount of coal required at 24 MBTU/ton would be 5,833 tons/year. From Chapter 9, the required amount of hay or straw would be (5,833 tons/year)(2.6) = 15,166 tons/year. Therefore, to meet the IAAP boiler fuel requirements, nearly 50% of the local hay and straw production would have to be diverted from animal feed purposes. This is considered to be unacceptably disruptive. However, an estimate of agricultural residue fuel costs was made as in Section 9-1. The cost of hay in 1981 from the Indiana Crop and Livestock Statistics (No. A 82-1) was $60.50/ton and alfalfa was $65.50/ton. No prices were given for wheat straw. However, because of the high prices for alfalfa and hay, straw cost was assumed to be at least $40/ton.

CALCULATION OF TOTAL RESIDUE COST

Hay/Straw Cost (average)	$50.00/ton
Transportation Cost	$ 5.60/ton
Total Cost at Pile	$55.60.ton

The boiler fuel energy input = 140,000 MBTU/year. At 80% boiler efficiency, the steam output is 112,000 MBTU/year. The cost of this steam is ($55.60/ton)(15,166 tons)/112,000 MBTU = $7.52/MBTU Steam.

Because 2.6 tons of straw are required per ton of coal, the equivalent cost of coal would be (2.6)($55.60) = $144.56/ton whereas coal is available delivered to IAAP at $49/ton.

As in Section 9-1, the boiler site fuel handling cost was assumed to be twice that of wood fuel or (2)($11.22/ton) = $22.40/ton.

TABLE 9-1

POTENTIALLY COLLECTIBLE AGRICULTURAL CROP RESIDUE

	Acres Planted by County*						Annual Residue		
Crop	Clark	Floyd	Wash-ington	Scott	Jeffer-son	Total	Residue Factor**	Tons of Residue	Tons of Collectible Residue+
Corn	26,300	3,300	60,500	21,300	24,200	135,600	2.46	333,576	83,394
Soybeans	23,200	3,100	9,900	10,000	22,100	68,300	1.26	86,058	21,515
Oats	200	100	900	100	300	1,600	1.61	2,576	644
Wheat	3,700	1,300	11,000	1,900	3,700	21,600	1.45	31,320	7,830
Hay	11,900	5,000	21,700	5,000	11,400	55,000	1.69	92,950	23,238
							Totals	546,480	136,621

Sources

* Purdue University Cooperative Extension Service
**Purdue University, Department of Agricultural Engineering
\+ Approximately 25 percent of Total Residue

CHAPTER 10

BIOMASS EQUIVALENT OF COAL

The energy equivalence of biomass fuel to coal is a major concern of this study. At each AAP, the primary fuel being considered for a new central boiler plant is coal. Thus, all of the various biomass fuels being considered to replace coal must be evaluated in terms of cost/ton, energy content/lb and combustion (boiler) efficiency. Some of these values are listed in Table 10-1 below:

TABLE 10-1

RELATIVE BOILER FUEL CHARACTERISTICS

Fuel	Energy (Btu/lb)	Boiler Effc. (%)
Bituminous Coal	12,000	80
Sawmill Waste	4,674	68.86
Green Wood Chips	4,674	68.86
Hay or Straw	6,000	77
Processed Wood Pellets	8,000	80
Energy Forest Chips	6,880	80

It has been stated earlier herein that the moisture content of biomass fuel is a major factor in the economics of boiler operation. The moisture content of biomass (particularly that of wood) can be expressed in two ways. The method used by wood and forest technologists is most often the "oven dry weight" or ODW method. In this concept, the % moisture level is given as the proportion of water to the oven dry weight of the wood. Thus, 100% ODW moisture means that the weight of the water equals the weight of wood that would exist if all the free moisture was removed. It is possible for the moisture in some woods to exceed the dry basis weight by 150% or more. Table 10-2 below shows some of the typical green (as-cut) moisture contents of common North American species.

TABLE 10-2

DENSITY AND GREEN MOISTURE CONTENT FOR SOME TYPICAL NORTH AMERICAN SPECIES

Species	Specific[1] Gravity	Green[2] Moisture Content (%)	Green Density (O.D.Wt/Green Vol. (lbs/ft^3)	Water Per. Unit Vol. (lbs/ft^3)
Softwoods				
Douglas fir				
Old growth	.45	45	28.1	12.6
Second growth	.45	60	28.1	16.8
Englemann Spruce	.32	60	20.0	12.0
Ponderosa Pine	.38	100	23.7	23.7
Southern Yellow Pine	.47	100	29.3	29.3
Western Hemlock	.38	100	23.7	23.7
Hardwoods				
Northern Red Oak	.56	80	34.9	27.9
Red Alder	.37	100	23.1	23.1
Yellow Birch	.55	75	34.3	25.7
Yellow Poplar	.40	90	25.0	22.5

[1]Based on O.D. weight and green volume

[2]Approximate values from Wood Handbook (Dry weight basis)

Engineers and others who are primarily interested in the combustion of fuels rather than the production of timber and wood products, use a moisture content scale that is based on the total weight (green weight) of the wood. Thus, when half of the total weight (dry wood plus water) of a wood sample is represented by water, the green weight (GW) moisture content is 50%. This corresponds to an oven dry weight (ODW) moisture content of 100%. Conversion between the two systems is given below:

$$\% \text{ Moisture Content (MC) ODW} = \frac{100 \times \text{MC \% GW}}{100 - \text{MC \% GW}}$$

$$\% \text{ Moisture Content (MC) GW} = \frac{100 \times \text{MC \% ODW}}{100 + \text{MC \% ODW}}$$

Figure 10-1 is a convenient tool to make either conversion.

Once the moisture content of the biomass fuel has been ascertained, it is convenient to estimate its energy content on a green or as-received basis. Oven dry fuel is practically unavailable. Waste from processing kiln-dried lumber may be available in small quantities and will have a GW moisture content of around 10%. However, in the Eastern U.S., the most available wood fuel source is that of whole tree chips or green mill residue having moisture contents of 80% to 100% ODW basis (Table 10-2) which is 44% to 50% GW basis. Fortunately for calculation of wood energy content, most of the common Eastern U.S. hardwoods and softwoods have oven dry energy contents of approximately 8,600 Btu/lb. Thus, the energy content of these woods in the green condition is 8,600 Btu/lb reduced by 44% to 50% moisture (GW basis). Whole tree chips and bark may slightly exceed this value and wet sawdust could be somewhat lower in energy content.

Like wood, coal has two possible values for energy content. The laboratory (oven dry) analysis of bituminous coal yields an energy content of 13,000 Btu/lb to 13,500 Btu/lb. There is some energy variation due to the source of this coal (Southern Illinois, Eastern Kentucky, Kansas, etc.). The coal contains some moisture when mined and may acquire more when crushed and transported. Thus, the as-received energy content of Eastern bituminous coal is generally listed as 12,000 Btu/lb. When this coal is burned in a modern medium size boiler, the boiler efficiency is approximately 80%. The boiler efficiency is strongly dependent on the steam content of the stack gases, which represents an energy loss of about 1,200 Btu/lb. Thus, wood with a moisture content greater than about 20% cannot be burned at the same boiler efficiency as that of bituminous coal. Therefore, boiler fuels cannot always be compared cost-wise solely on a basis of energy content in \$/MBTU. The true measure of fuel cost for boiler operation is \$/MBTU Steam. This basis is used herein.

An approximation of the variation of boiler efficiency with biomass fuel moisture content is given in Figure 10-2.

A more accurate calculation of the energy content, moisture content and boiler efficiency for wood fuels can be accomplished by surveying several batches of fuelwood typical of the sawdust, bark and whole tree chips expected to be used at the boiler sites (three AAPs).

AD-A150 814 BIOMASS FEASIBILITY STUDY FOR MILAN INDIANA AND KANSAS ARMY AMMUNITION PL..(U) ALABAMA UNIV IN HUNTSVILLE KENNETH E JOHNSON ENVIRONMENTAL AN.. G R GUINN ET AL. APR 83 UAH-357 HNDTR-83-66-ED-PM 2/2

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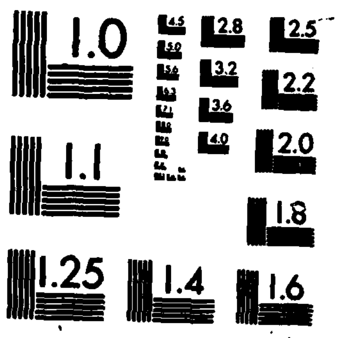

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

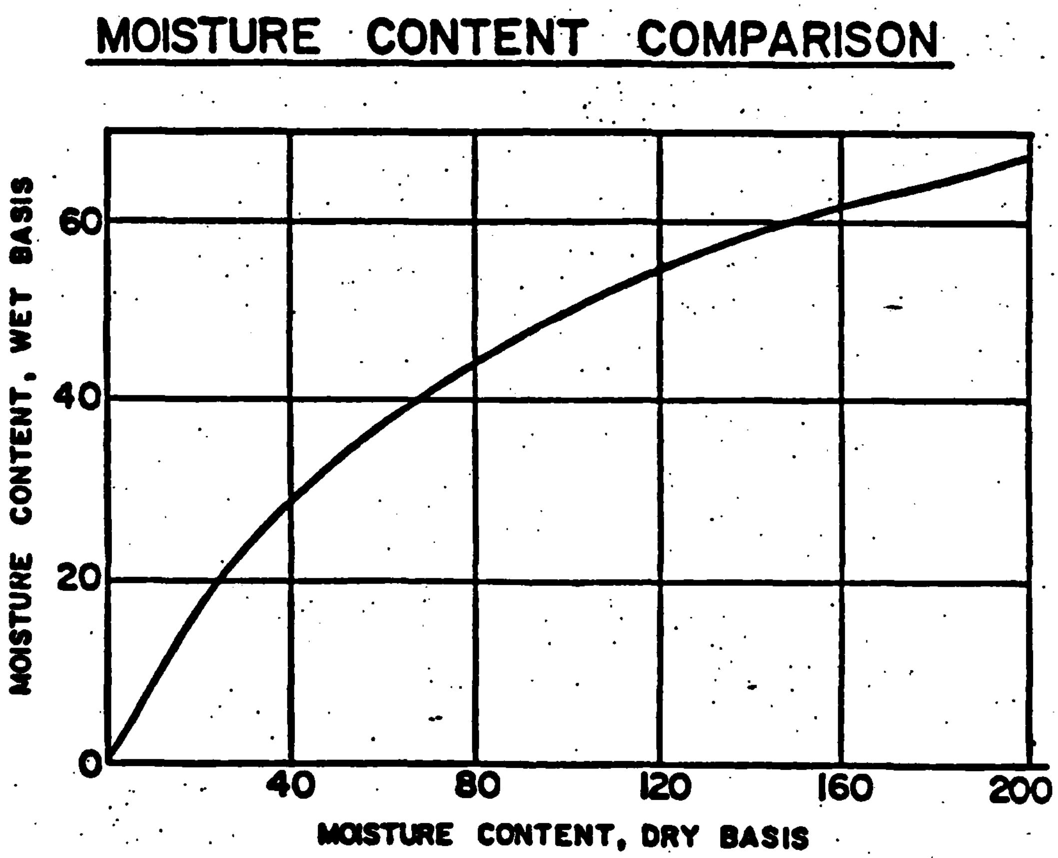

FIGURE 10-1. MOISTURE CONTENT COMPARISON

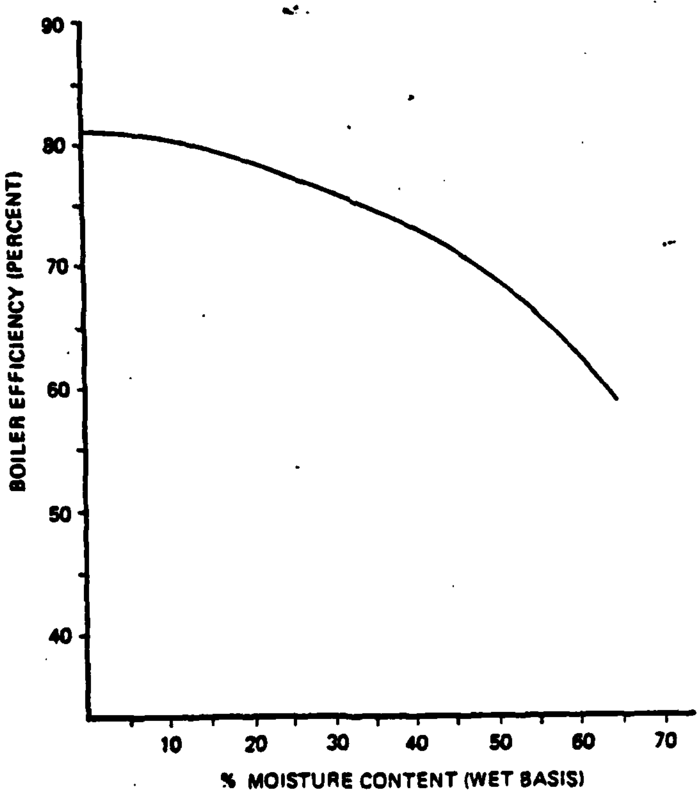

FIGURE 10-2. THE EFFECTS OF FUEL MOISTURE CONTENT ON BOILER EFFICIENCY

This was done by A.B. Curtis, Jr. using data from Report No. 1666-18, Forest Products Laboratory, USDA Forest Service, 1960, by L.H. Reineke. Mr. Curtis is the forestry consultant for this study, and is a wood energy specialist at the USDA Forest Service in Jackson, Mississippi. The average moisture content of 21 samples of waste wood fuel was found to be 45.6%. Using this data, it is possible to enter a table of wood energy content (Table 10-3) based on standard combustion calculations to derive both heat of combustion and usable (boiler) efficiency of the fuelwood. From this table, the energy content of fuelwood at 45.6% moisture (green basis) is seen to be 4,674 Btu/lb whereas the boiler efficiency is 68.86%. These values are somewhat higher than those typical of the literature on industrial wood combustion and also some of the studies of other AAPs. These sources quote values of 4,300 Btu/lb, 50% moisture and 65% boiler efficiency. However, the numbers derived by A.B. Curtis are considered specific for the three AAPs in this study and are used herein.

Using Table 10-3 with fuelwood (mill waste and whole tree chips) characteristics of 4,674 BTU/lb and 68.86% boiler efficiency, the ratio of wood fuel required to replace coal is:

$$\frac{\text{wood}}{\text{coal}} = \frac{(12{,}000\ \text{BTU/lb})(80\%)}{(4{,}674\ \text{BTU/lb})(68.86\%)} = 2.983$$

This ratio should be rounded off to 3.0.

Based on coal requirements, the wood fuel requirements are:

KAAP wood fuel = 3(12,000 tons/year) = 36,000 tons/year
MAAP wood fuel = 3(9,860 tons/year) = 29,580 tons/year

For IAAP the annual energy requirements are one million gallons of fuel oil (140,000 MBTU). At 24 MBTU/ton for coal, this is 5,833 tons.

IAAP wood fuel = 3(5,833 tons/year) = 17,499
= 17,500 tons/year

When trees are grown for fuel in an energy forest, they are allowed to field-dry for six months after being cut down. Because of their small diameters (usually 3" to 6") these trees will air dry to a moisture content of 20% (green basis). Thus the energy content of the whole tree chips made from this wood is 8,600 (0.8) = 6,880 BTU/lb.

Processed wood pellets are oven-dried before sale, reducing moisture content to about 7%. The energy content of these fuels is (8,600(0.93) = 7,998 = 8,000 BTU/lb.

TABLE 10-3

HEAT AVAILABLE FROM ONE POUND OF WOOD RESIDUE, BY MOISTURE CONTENT
GROSS HEAT FROM ONE LB. (OVEN DRY) ASSUMED AT 8600. BTU'S
(Data from Texas Forest Service)

Moisture Content Dry Basis (%)	Moisture Content Wet Basis (%)	Dry Weight (Lbs.)	Water Weight (Lbs.)	Heat of Combustion (BTU)	Water Evap. (BTU)	Hydrogen Loss (BTU)	Flue Loss (BTU)	Yield Before Boiler (BTU)	5% Boiler Loss (BTU)	Yield After Boiler (BTU)	Oven Dry To Usable Eff. (%)
61.0000	37.8882	0.6211	0.3789	5341.61	458.45	409.94	428.57	4044.66	202.23	3842.43	71.9338
62.0000	38.2716	0.6173	0.3827	5308.64	463.09	407.41	425.93	4012.22	200.61	3811.61	71.8001
63.0000	38.6503	0.6135	0.3865	5276.07	467.67	404.91	423.31	3980.18	199.01	3781.17	71.6665
64.0000	39.0244	0.6098	0.3902	5243.90	472.20	402.44	420.73	3948.54	197.43	3751.11	71.5328
65.0000	39.3939	0.6061	0.3939	5212.12	476.67	400.00	418.18	3917.27	195.86	3721.41	71.3991
66.0000	39.7590	0.6024	0.3976	5180.72	481.08	397.59	415.66	3886.39	194.32	3692.07	71.2655
67.0000	40.1198	0.5988	0.4012	5149.70	485.45	395.21	413.17	3855.87	192.79	3663.07	71.1318
68.0000	40.4762	0.5952	0.4048	5119.05	489.76	392.86	410.71	3825.71	191.29	3634.43	70.9981
69.0000	40.8284	0.5917	0.4083	5088.76	494.02	390.53	408.28	3795.92	189.80	3606.12	70.8645
70.0000	41.1765	0.5882	0.4118	5058.82	498.24	388.24	405.88	3766.47	188.32	3578.15	70.7308
71.0000	41.5205	0.5848	0.4152	5029.24	502.40	385.96	403.51	3737.37	186.87	3550.50	70.5972
72.0000	41.8605	0.5814	0.4186	5000.00	506.51	383.72	401.16	3708.60	185.43	3523.17	70.4635
73.0000	42.1965	0.5780	0.4220	4971.10	510.58	381.50	398.84	3680.17	184.01	3496.16	70.3298
74.0000	42.5287	0.5747	0.4253	4942.53	514.60	379.31	396.55	3652.07	182.60	3469.47	70.1962
75.0000	42.8571	0.5714	0.4286	4914.29	518.57	377.14	394.29	3624.29	181.21	3443.07	70.0625
76.0000	43.1818	0.5682	0.4318	4886.36	522.50	375.00	392.05	3596.82	179.84	3416.98	69.9288
77.0000	43.5028	0.5650	0.4350	4858.76	526.38	372.88	389.83	3569.66	178.48	3391.18	69.7952
78.0000	43.8202	0.5618	0.4382	4831.46	530.22	370.79	387.64	3542.81	177.14	3365.67	69.6615
79.0000	44.1341	0.5587	0.4413	4804.47	534.02	368.72	385.47	3516.26	175.81	3340.44	69.5278
80.0000	44.4444	0.5556	0.4444	4777.78	537.78	366.67	383.33	3490.00	174.50	3315.50	69.3942
81.0000	44.7514	0.5525	0.4475	4751.38	541.49	364.64	381.22	3464.03	173.20	3290.83	69.2605
82.0000	45.0549	0.5495	0.4505	4725.27	545.16	362.64	379.12	3438.35	171.92	3266.43	69.1269
83.0000	45.3552	0.5464	0.4536	4699.45	548.80	360.66	377.05	3412.95	170.65	3242.30	68.9932
84.0000	45.6522	0.5435	0.4565	4673.91	552.39	358.70	375.00	3387.83	169.39	3218.43	68.8595
85.0000	45.9459	0.5405	0.4595	4648.65	555.95	356.76	372.97	3362.97	168.15	3194.82	68.7259
86.0000	46.2366	0.5376	0.4624	4623.66	559.46	354.84	370.97	3338.39	166.92	3171.47	68.5922
87.0000	46.5241	0.5348	0.4652	4598.93	562.94	352.94	368.98	3314.06	165.70	3148.36	68.4585
88.0000	46.8085	0.5319	0.4681	4574.47	566.38	351.06	367.02	3290.00	164.50	3125.50	68.3249
89.0000	47.0899	0.5291	0.4709	4550.26	569.79	349.21	365.08	3266.19	163.31	3102.88	68.1912
90.0000	47.3684	0.5263	0.4737	4526.32	573.16	347.37	361.16	3242.63	162.13	3080.50	68.0576

Hay or straw can be used as boiler fuel. However, the moisture content at harvest (about 14%) tends to increase to about 20% by the time the fuel is burned. Thus the as-fired energy content is about 6,000 BTU/lb (Reference 9).

The data just described are presented in Table 10-4 below:

TABLE 10-4

AS-RECEIVED MOISTURE IN BIOMASS FUELS

Fuel	Moisture % (GW Basis)
Green Sawmill Waste (Sawdust/Bark)	45.6
Green Wood Chips (Slash or Whole Tree)	45.6
Hay or Straw	20
Processed Wood Pellets	7%*
Energy Forest Chips	20

*Assumes no moisture gain after manufacture

CHAPTER 11

ENERGY REQUIRED TO PROVIDE BIOMASS FUELS

One of the requirements of this study was to determine the consumption of other forms of energy such as petroleum-based fuel necessitated by the harvesting, collection and transportation of biomass fuels for the three Army Ammunition Plants (AAPs). The purpose of this exercise is to ensure that, in replacing coal with a less expensive fuel (biomass), there is no net unfavorable use of more critical sources of energy in the country. To a large degree, this problem is negated by economics. That is, electrical energy and petroleum-based fuels cost more than coal, at least in the region of the subject AAPs. Thus no biomass fuel could be cheaper than coal if its production and transportation entailed consumption of significant amounts of more expensive fuels than coal. Nevertheless, in this study the petroleum and electric energy consumption related to the biomass fuels of interest was assessed. The boiler site fuel handling energy is all electric. This energy requirement is not included in this chapter because of lack of coal handling data for comparison.

11-1 KANSAS AAP BIOMASS FUEL PRODUCTION ENERGY

The adequate or marginal sources of biomass fuel for the Kansas AAP consist of forest residue (slash), agricultural residue (wheat straw), off-site whole tree chips and an AAP fuelwood plantation (Table 2-3). There does not appear to be any point in further cost estimates for the biomass fuel types that are of inadequate quantities.

a. Forest Residue. Forest residue or slash is harvested and transported by the same equipment described in Table 5-2. From this table the total cost of fuel (Diesel) used was \$1.98/ton and at \$1.10/gal. (Table 5-1), this fuel usage is 1.8 gallons/ton.

One gallon of Diesel fuel contains 140,000 BTUs. Thus the slash collection and transportation energy is (1.8 gal.)(140,000 BTU/gal) = 252,000 BTU/ton. Because 36,000 tons/year are required, the total energy is $9,072 \times 10^6$ BTU. This energy is used to help replace 12,000 tons of coal at 24×10^6 BTU/ton which yields totals $288,000 \times 10^6$ BTU. Thus the oil energy cost of replacing coal with forest residue is less than 1/30 of the energy of the coal.

b. Agricultural Residue. The agricultural residue of interest at KAAP is wheat straw. It is assumed that this material is normally turned under the soil after wheat harvesting. Therefore, the on-farm energy cost of handling this fuel consists of baling, loading round bales on a flatbed wagon, towing the wagon to a road, unloading

the bales and then loading the semitrailer when it arrives. A baler operated by a 120 horsepower tractor can produce 16 1,500 pound bales per hour. A 100 horsepower front-end loader can load four bales on a farm wagon and accompany the wagon while carrying a fifth bale on a ½ mile round trip to the road where the bales are unloaded by the frontend loader. The round trip at six miles per hour takes (½)/6 = 1/12 hour = five minutes. Loading and unloading takes a total of five minutes, so the cycle time is 10 minutes to handle five bales, a rate of 30 bales/hr. To load the semitrailer will require 2½ minutes for each five bales or 120 bales/hour. The tractor pulling the flatbed trailer is a 100 hp unit. It is now possible to calculate the horsepower-hours per bale:

Baling:	(120 hp)/(16 bales/hour) =	7.50 hp-hr/bale
Transportation:	(200 hp)/(20 bales/hour) =	10.00 hp-hr/bale
Loading Semitrailer:	(100 hp)(120 bales/hour) =	0.83 hp-hr/bale
Total:		18.33 hp-hr/bale

Because one bale weighs 1,500 lb (3/4 ton), then 18.33 hp-hr/bale = 24.44 hp-hr/ton. From Table 5-1, gallons/hour of Diesel fuel are 0.037 x hp. Thus, gallons/ton = (0.37)(24.44) = 9.04. At 140,000 BTU/gal, the energy use is 126,560 BTU/ton. To this must be added the energy to transport the straw to the KAAP. Because of the low bulk density of round straw bales, this energy was assumed to be twice as great as that of forest residue (Section 10-1 b.) so this value is (2)(380,800 BTU/ton) = 761,600 BTU/ton. The total energy/ton = 761,600 BTU/ton plus 126,560 BTU/ton = 888,160 BTU/ton.

From Section 9-1, 31,200 tons/year of straw are needed at KAAP to replace 12,000 tons (288,000 x 10^6 BTU) of coal. (31,200 tons)(888,160 BTU/ton) = <u>27,711 x 10^6 BTU</u>.

c. <u>Off-Site Whole Tree Chips</u>. As was shown in Chapters 5 and 6, the cost of wood chips from slash or whole trees is the same when the transportation distances are the same. Thus the BTU requirements of this section are the same as in Section 11-1 a.

d. <u>AAP Fuelwood Plantation</u>. As explained in Chapter 8, the costs of the fuelwood plantations are based on Gary Naughton's recent paper. This paper does not break out the fuel costs for harvesting. However, personal conversation with Naughton indicated that his operations were based on a labor-intensive arrangement wherein chainsaws and other light duty equipment were used. Therefore, it is estimated

herein that the fuel usage for harvesting the fuelwood plantation should be only half that used for whole tree chipping to harvest approximately the same amount of wood fuel with conventional equipment (Table 5-7). Also, it is assumed that once the fuelwood plantation chips were loaded on trucks, the transportation fuel usage would be the same as for the other types of wood chips produced on-site.

To calculate the on-site transportation fuel usage, it is necessary to first calculate the tons/year of fuelwood chips to be transported from the fuelwood plantation an average of 10 miles to the boiler site. The field-dried fuelwood chips (20% moisture) contain (8,600 BTU/lb)(.8) = 6,880 BTU/lb. The coal usage for the KAAP central boiler plant was calculated to be 12,000 tons/year of 12,000 BTU/lb coal. Thus the fuelwood requirement is 12,000 tons/year (12,000/6,880) = 20,930 tons/year. The round trip of the trucks is 20 miles and they average 6 miles/gal. The trucks carry 23 tons and the number of trips is 20,930/23 = 910. The number of miles driven is (910)(20) = 18,200. At 6 miles per gallon, this is 3,033 gallons of Diesel fuel. At 140,000 BTU/gal, the energy usage is 425 x 10^6 BTU.

The harvesting fuel cost/ton from Table 5-7 is $2.52/ton or 2.29 gal/ton for $1.10/gal Diesel fuel. It was estimated earlier that use of ½ of this fuel usage is appropriate. Thus, the annual harvesting energy is (140,000 BTU/gal)(20,930 tons)(½)(2.29) = 3,356 x 10^6 BTU. Adding this to 425 x 10^6 BTU gives a total harvesting and transportation energy usage of 3,781 x 10^6 BTU.

e. Summary of Energy Requirements. The summary of the energy requirements for harvesting and transporting biomass fuel for KAAP is presented in Table 11-1 below:

TABLE 11-1

ENERGY REQUIRED TO PROVIDE KAAP BIOMASS FUEL

Type of Biomass	Coal Energy Replaced by Biomass Fuel (BTU x 10^6)	Diesel Fuel Energy Required (BTU x 10^6)
Forest Residue	288,000	9,072
Agricultural Residue	288,000	27,711
Off-Site Tree Chips	288,000	9,072
AAP Fuelwood Plantation	288,000	3,781

11-2 MILAN AAP BIOMASS FUEL PRODUCTION ENERGY

THe adequate or marginal biomass fuel sources for MAAP are sawdust and bark, forest residue, existing AAP forest, off-site whole tree chips and an AAP fuelwood plantation (Table 3-3).

a. Sawdust and Bark. Sawmill residue (sawdust and bark) require only transportation energy (Diesel fuel) in order to be delivered to the MAAP. This is true because this residue is a byproduct of lumber production and would be produced even if there was no market for the residue (which is often the case). For the MSR fuel requirements at MAAP, the annual quantity of sawdust and bark is 29,580 tons (Section 3-1). To transport this material in 23 ton semitrailer loads requires 1,286 trips. At 70 miles per round trip, total miles driven are 90,026. The trucks average 6 miles per gallon and thus consume 15,004 gallons. Each gallon contains 140,000 Btu so total energy usage is $2,101 \times 10^6$ BTU. The energy of the coal replaced by the sawdust and bark is (9,860 tons)(24×10^6 BTU/ton) = $236,640 \times 10^6$ BTU.

b. Forest Residue. Forest residue (slash) requires the same amount of energy to harvest and transport as does whole tree chips (Table 5-5). This value is \$2.29/ton or 2.08 gal/ton for \$1.10/gal Diesel fuel. Diesel fuel contains 140,000 BTU/gal so the total annual energy usage is (140,000)(2.08)(29,860) = $8,695 \times 10^6$ BTU.

c. Existing AAP Forest. The costs for harvesting and transporting wood chips from the existing forest at MAAP are \$1.89/ton from Table 5-4. This is 1.72 gal/ton at \$1.10/gal. The total annual energy usage of Diesel fuel = (140,000)(1.72)(29,860) = $7,190 \times 10^6$ BTU.

d. Off-Site Whole Tree Chips. As was stated in Section 11-2 b., the energy requirements of harvesting and transporting wood chips to the AAPs is the same for forest residue or whole trees so the cost for whole tree chips is the same as in 11-2 b., ($8,695 \times 10^6$ BTU).

e. AAP Fuelwood Plantation. The energy usage associated with an AAP fuelwood plantation were given in Section 11-1 b., for KAAP. The same rationale will be used for MAAP. The energy requirements for producing fuelwood chips is in proportion to the energy of the coal these chips replace. The ratio of coal usage MAAP/KAAP is 9,860/12,000 = 0.8217. Thus the cost of providing fuelwood chips at the MAAP central boiler house is (0.8217)($3,781 \times 10^6$ BTU) = $3,107 \times 10^6$ BTU (Section 11-1 b.).

f. Summary of Energy Requirements. The summary of the energy requirements for harvesting and transporting biomass fuel for MAAP is presented in Table 11-2 below:

TABLE 11-2

ENERGY REQUIRED TO PROVIDE MAAP BIOMASS FUEL

Type of Biomass	Coal Energy Replaced by Biomass Fuel (BTU x 10^6)	Diesel Fuel Energy Required (BTU x 10^6)
Sawdust and Bark	236,640	2,101
Forest Residue	236,640	8,695
Existing AAP Forest	236,640	7,190
Off-Site Tree Chips	236,640	8,695
AAP Fuelwood Plantation	236,640	3,107

11-3 INDIANA AAP BIOMASS FUEL PRODUCTION ENERGY

The adequate or marginal sources of biomass fuel for the Indiana AAP consist of sawmill residue (sawdust and bark), forest residue (slash), agricultural residue (hay and straw) and off-site whole tree chips.

a. Sawdust and Bark. Sawmill residue (sawdust and bark) is the lowest cost biomass fuel option for IAAP and, as shown in Section 11-2 a., has a very low transportation energy usage of 2,101 x 10^6 BTU for the 29,860 tons/year of fuel needed for MAAP. Thus, to determine the energy to transport the 17,500 tons/year needed for IAAP, it is only necessary to multiply 2,101 x 10^6 BTU by the ratio of wood fuel requirements to get 1,231 x 10^6 BTU. The energy value of the coal replaced is (5,833 tons)(24 MBTU/ton) = 139,992 x 10^6 BTU.

b. Forest Residue. Forest residue (slash) requires the same amount of energy (Diesel fuel) to harvest and transport wood fuel as do whole tree chips so the data from Table 5-7 may be used for this calculation. This value is $3.00/ton or 2.73 gal/ton for $1.10/gal Diesel fuel. Diesel fuel contains 140,000 BTU/gal, so the total annual energy usage is (140,000 BTU/gal)(2.73 gal/ton)(17,500 ton/year) = 6,688 x 10^6 BTU.

c. Agricultural Residue. Agricultural residue (hay and straw) are available for boiler fuel at IAAP. The energy costs of

collecting and transporting this type of residue have already been calculated for the fuel requirements of KAAP (Section 11-1 b.). At KAAP, biomass fuel must replace 12,000 tons/year of coal whereas at IAAP, the amount is 5,833 tons/year (Section 5-5). Therefore, to calculate the total energy needed to provide agricultural residue fuel to IAAP it is only necessary to multiply the value for IAAP by the ratio of coal fuel requirements ($27,711 \times 10^6$ BTU)(5,833/12,000) = <u>$13,470 \times 10^6$ BTU</u>.

d. <u>Off-Site Whole Tree Chips</u>. As stated in Section 11-3 b., this energy usage to provide off-site whole tree chips to the IAAP is the same as that calculated for off-site slash chips and thus is <u>$6,688 \times 10^6$ BTU</u>.

e. <u>Summary of Energy Requirements</u>. The summary of the energy requirements for harvesting and transporting biomass fuel to IAAP is presented in Table 11-3 below:

TABLE 11-3

ENERGY REQUIRED TO PROVIDE IAAP BIOMASS FUEL

Type of Biomass	Coal Energy Replaced by Biomass Fuel (BTU x 10^6)	Diesel Fuel Energy Required (BTU x 10^6)
Sawdust and bark	139,992	1,231
Forest Residue	139,992	6,688
Agricultural Residue	139,992	13,470
Off-Site Whole Tree Chips	139,992	6,688

11-4 CONCLUSION

As might be expected, the biomass fuel requiring the least energy to harvest and transport to the AAPs is sawdust and bark, which have no harvesting cost assigned to them because they are byproducts of lumber production. The energy required to transport sawdust and bark 35 miles to an AAP is less than 1% of the energy replaced by the biomass fuel (Tables 11-2 and 11-3). In comparison, collection and transportation of agricultural residue (primarily hay and straw) is the most energy-intensive. It requires about 10% of the energy replaced by this fuel to collect it and transport it 35 miles.

To provide wood chip fuel from an existing AAP forest (Table 11-2) is intermediate in energy costs. The energy required to harvest and transport this fuel 10 miles represents about 3% of the energy content of the coal replaced by the fuelwood. This option requires only slightly less energy (Diesel fuel) than does the off-site whole tree chips brought an additional 25 miles per load because the harvesting energy is the major fuel requirement.

On a \$/BTU basis, Diesel fuel at \$1.10/gal. is 4.5 times as expensive as coal at \$42/ton. Therefore, the Diesel fuel energy needed to produce and transport a biomass fuel cannot possibly be more than about 1/5 as great as the coal energy replaced if the biomass fuel is to be cost-competive with coal.

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APPENDIX A

KSU
KANSAS STATE UNIVERSITY

Cooperative Extension Service

State and Extension Forestry
2610 Claflin Road
Manhattan, Kansas 66502
913-532-5752

February 2, 1981

Mr. Will Cook
Kansas Army Ammunition Plant
Parsons, KS 67357

Dear Will:

Enclosed you will find information relating to wood resources available within a 50 mile radius of Parsons. Manufacturing residue will amount to about 20,000 tons annually within the same radius of Parsons and should be available.

The development of fiber for fuel could also be attained through plantations on plant property. The two publications, Firewood Plantations and The University of Kansas Energy Forest Report addresses the plantation and Btu potential for wood quite thoroughly.

I trust this information will be helpful and if I can be of additional help contact me at any time.

Sincerely,

Len Gould

Leonard K. Gould
Extension Forester
Utilization and Marketing

LKG/plp

cc: Bill Jackson, Co. Ext. Agril. Agent

Enclosure

APPENDIX B

100% TIMBER CRUISE
OF KANSAS ARMY AMMUNITION PLANT WOODLANDS

BY

JACK ROWLAND

AREA EXTENSION FORESTER

1981-82
Stand Volume
100% Cruise

Compartment I

Species	No. of Trees	Grade	Est. Bd. Ft. /Doyle Rule
*Red Oak	352		56,584
Bur Oak	54		11,286
Elm	55		11,946
Cottonwood	26		11,220
Sycamore	32		6,402
Ash	50		5,984
Hackberry	33		4,840
Maple	32		6,534
Hickory	35		4,884
Kentucky Coffeetree	12		704
Boxelder	16		946
Walnut	204	Prime	11,488
		Select	6,229
		No. 2	12,895
TOTAL	901		151,942

Species by Diameter Class (DBH) and Volume

Compartment I

	14"	16"	18"	20"	22"	24+"	TOTAL
*Red Oak	2,618	3,982	3,850	8,954	7,612	29,568	56,584
Bur Oak	-	44	814	2,090	2,420	5,918	11,286
Elm	-	484	1,012	1,562	770	8,118	11,946
Cottonwood	-	88	616	638	1,210	8,668	11,220
Sycamore	44	418	704	1,254	572	3,410	6,402
Ash	264	682	1,738	1,672	176	1,452	5,984
Hackberry	-	264	880	1,738	836	1,122	4,840
Maple	-	198	506	2,948	1,210	1,672	6,534
Hickory	44	242	1,474	1,760	1,034	330	4,884
Kent. Coffeetree			506	198			704
Boxelder		242	110	198	396		946
SUB-TOTAL	2,970	6,644	12,210	23,012	16,236	60,258	121,330

	14-15"	16-17"	18-19"	20-21"	22-23"	24+"	TOTAL
WALNUT	206	2,291	4,889	8,630	7,935	6,661	30,612

TOTAL 151,942

*Red Oak includes Pin Oak and Northern Red Oak

1981-82
Stand Volume
100% Cruise

Compartment II

Species	No. of Trees	Grade	Est. Bd. Ft. /Doyle Rule
*Red Oak	219		38,071
Post Oak	39		4,334
Pecan	13		2,046
Bur Oak	87		16,676
Hackberry	38		4,510
Sycamore	16		2,882
Elm	55		6,930
Ash	33		5,522
Hickory	40		6,138
Cottonwood	18		2,640
Maple	4		726
Kentucky Coffeetree	5		374
Willow	5		418
Boxelder	2		198
Walnut	48	Prime	3,271
		Select	2,518
		No. 2	4,353
TOTAL	622		101,607

Species by Diameter Class (DBH) and Volume

Compartment II

	14"	16"	18"	20"	22"	24+"	TOTAL
*Red Oak	2,255	2,794	4,290	7,480	5,698	15,554	38,071
Post Oak	176	792	770	1,012	462	1,122	4,334
Pecan	44	176	418	396	484	528	2,046
Bur Oak	44	308	770	4,136	4,774	6,644	16,676
Hackberry	330	286	1,188	1,188	946	572	4,510
Sycamore	44	176	374	858	308	1,122	2,882
Elm	396	682	836	1,100	1,782	2,134	6,930
Ash	154	594	858	1,936	1,320	660	5,522
Hickory	440	924	110	1,276	484	2,904	6,138
Cottonwood	-	242	484	550	1,122	242	2,640
Maple	-	88	154	198	-	286	726
Kent. Coffeetree	-	-	-	198	176	-	374
Willow	88	88	110	132	-	-	418
Boxelder	-	-	-	88	110	-	198
SUB-TOTAL	3,971	7,150	10,362	20,548	17,666	31,768	91,465

	14-15"	16-17"	18-19"	20-21"	22-23"	24+"	TOTAL
WALNUT	-	571	2,177	2,741	1,919	2,734	10,142

TOTAL 101,607

*Red Oak includes Pin Oak and Northern Red Oak

1981-82
Stand Volume
100% Cruise

Compartment III

Species	No. of Trees	Grade	Est. Bd. Ft. /Doyle Rule
Pecan	20	-	2,904
Hackberry	16	-	2,420
Elm	12	-	1,386
Ash	12	-	902
*Red Oak	6	-	550
Honeylocust	2	-	66
Osage-Orange	1	-	132
TOTAL	69		8,360

Species by Diameter Class (DBH) and Volume

Compartment III

	14"	16"	18"	20"	22"	24"+	TOTAL
Pecan	44	154		836	374	1,496	2,904
Hackberry	154	44	286		572	1,364	2,420
Elm	44	88	66	308		880	1,386
Ash	352		66	264		220	902
Red Oak		352	66	132			550
Honeylocust	22	44					66
Osage-Orange				132			132
TOTAL	616	682	484	1,672	946	3,960	8,360

*Red Oak includes Pin Oak and Northern Red Oak

1981-82
Stand Volume
100% Cruise

Compartment IV

Species	No. of Trees	Grade	Est. Bd. Ft. /Doyle Rule
Cottonwood	48		7,700
Hackberry	28		3,586
Elm	21		3,190
Pecan	8		1,408
*Red Oak	4		1,056
Willow	4		638
Ash	4		418
Honeylocust	4		330
Boxelder	2		220
Osage-Orange	1		132
Kentucky Coffeetree	1		44
Walnut	4	Prime	40
		Select	116
		No. 2	152
TOTAL	129		19,030

Species by Diameter Class (DBH) and Volume

Compartment IV

	14"	16"	18"	20"	22"	24"+	TOTAL
Cottonwood	550	726	660	968	1,320	3,476	7,700
Hackberry	110	176	660	1,474	286	880	3,586
Elm		88	506	748	286	1,562	3,190
Pecan			220	528	176	484	1,408
*Red Oak					440	616	1,056
Willow				528	110		638
Ash	44		154	220			418
Honeylocust	44			176	110		330
Boxelder					220		220
Osage-Orange							132
Kentucky Coffeetree	44						44
Walnut	104	51		153			308
TOTAL	896	1,041	2,200	4,795	2,948	7,018	19,030

*Red Oak includes Pin Oak and Northern Red Oak

1981-82
Stand Volume
100% Cruise

Compartment V

Species	No. of Trees	Grade	Est. Bd. Ft. /Doyle Rule
*Red Oak	10	-	1,584
Ash	7	-	572
Hackberry	4	-	528
Elm	4	-	352
Kentucky Coffeetree	3	-	396
Walnut	1	No. 2	261
TOTAL	29		3,693

Species by Diameter Class (DBH) and Volume

Compartment V

	14"	16"	18"	20"	22"	24"+	TOTAL
Walnut						261	261
*Red Oak		88	220	638	638		1,584
Ash		44	308	220			572
Hackberry				418	110		528
Elm		88	176	88			352
Kentucky Coffeetree				396			396
TOTAL		220	704	1,760	768	261	3,693

*Red Oak includes Pin Oak and Northern Red Oak

1981-82
Stand Volume
100% Cruise

Compartment VI

Species	No. of Trees	Grade	Est. Bd. Ft. /Doyle Rule
Walnut	4	Select	127
		No. 2	234
Cottonwood	23	-	3,564
Hackberry	28	-	1,738
Pecan	12	-	1,650
Elm	2	-	528
*Red Oak	1	-	242
Red Cedar	1	-	176
TOTAL	71		8,259

Species by Diameter Class (DBH) and Volume

Compartment VI

	14"	16"	18"	20"	22"	24"+	TOTAL
Walnut	92	88			181		361
Cottonwood	264	396	396	770	506	1,232	3,564
Hackberry	660	572	176	88	110	132	1,738
Pecan	176	242	220	132	264	616	1,650
Elm						528	528
*Red Oak						242	242
Red Cedar				176			176
TOTAL	1,192	1,298	792	1,166	1,061	2,750	8,259

*Red Oak includes Pin Oak and Northern Red Oak

1981-82
Stand Volume
100% Cruise

Compartment VII

Species	No. of Trees	Grade	Est. Bd. Ft. /Doyle Rule
Pecan	43	-	4,950
Hackberry	16	-	1,848
Cottonwood	11	-	2,200
Maple	4	-	440
Elm	1	-	132
Ash	1	-	100
TOTAL	76		9,670

Species by Diameter Class (DBH) and Volume

Compartment VII

	14"	16"	18"	20"	22"	24"+	TOTAL
Pecan	220	990	1,056	880	1,034	770	4,950
Hackberry	44	352	176	858		418	1,848
Cottonwood		242	154	396	682	726	2,200
Maple	44	198		198			440
Elm				132			132
Ash			110				110
TOTAL	308	1,782	1,496	2,464	1,716	1,914	9,680

APPENDIX C

AN ECONOMIC ANALYSIS OF ENERGY FOREST PLANTATIONS

G. G. Naughton and W. A. Geyer
Department of Forestry, Kansas State University
Manhattan, Kansas

AN ECONOMIC ANALYSIS OF ENERGY FOREST PLANTATIONS

G. G. NAUGHTON and W. A. GEYER
Department of Forestry, Kansas State University
Manhattan, Kansas 66502

Second EC Conference on Energy from Biomass, Berlin, Sept. 19-23, 1982

Summary

This paper shows a method for estimating the "least cost" approach in energy forest plantation systems. It uses a matrix analysis of the cost variables against the effects of time on yield within the constraints of tested silvicultural techniques. The data are from empirical studies in the central United States.

The independent variables are those which are set by competitive market forces beyond the control of the manager: land rent, the unit cost of materials, and the price of alternative fuels. The dependent variables are represented by the manager's choices in the establishment of the plantation: tree species, stocking rates, intensity of site preparation, weed control and selection of the cutting cycles.

The results show that the per unit area energy yield and the unit cost of energy produced both increase as plant density increases; while the number of years to obtain maximum yield and the area required to produce a specified volume of fuel decrease. The "least cost" system incorporates lower plant density (about 1400 trees per hectare), intensive weed control and coppice harvest cycles.

1. INTRODUCTION

The successful energy forest plantation must be a carefully planned and manipulated combination of efforts to capture the greatest amount of biological potential at the least cost per unit of production. Careful matching of available sites to proper combinations of species, spacing, cultural practices, and timing of the harvest can produce industrial wood fuels that are competitive with the cost of fossil fuels.

But, we must be cautious. Natural gas, oil and coal provide popular alternatives to wood fuels. These fossil fuels not only set the competitive price level for wood, they in fact dictate that wood usually must be available at lower cost if the user must spend money to retrofit his system to burn wood.

It costs money to produce wood fuel from energy forest plantations. The high number of stems per hectare normally recommended leads to high establishment costs. Compound interest rates must be charged against this investment.

A common problem of economic analysis is that, as soon as actual values are used in a formula, the solution becomes temporal. On the other hand, purely theoretical analysis is less likely to be put to effective use. We have therefore chosen to develop an empirical case. Even though the solution is locked into only one point in time, it's approach becomes a working model for plantation managers.

2. THE EXAMPLE CASE

Data for this analysis are taken from a six-year-old energy forest plantation complex of 5.0 hectares on three separate sites in northeastern Kansas. Aggregate averages of costs and yields are used to show average conditions for the geographic area.

Variable spacing trials were established to test plantation densities of 1400 to 7000 trees per hectare. Species evaluated were cottonwood, silver maple, black locust, and Siberian elm. Nondestructive sampling was used to estimate biomass yield using the D^2H system suggested by Bowersox and Murphey (1).

All measurements were standardized to ovendry weight. Cottonwood was used in this model because it showed the least overall variation between the 3 sites tested. Gross yields of cottonwood, silver maple, and black locust were similar, with silver maple showing the greatest variation. Siberian elm did not perform competitively on the sites tested.

Site preparation included fall plowing of grass sod followed by disking twice prior to spring planting. Casoron (dichlobenil) in 50% wettable powder formulation was applied at the rate of 8 kilograms per hectare following planting. Retreatment prior to the start of the second growing season included disking followed by a second application of Casoron.

3. ASSUMPTIONS

Each plantation system must be evaluated on its own characteristics. The conditions and assumptions of this example case are as follows:

<u>Land rent</u>: The sites were in prairie grasses prior to conversion to energy forest plantations. Annual property taxes were $10 per hectare and revenues (rent) $80 per hectare. The plantations must pay both costs for a total of $90 per hectare per year.

<u>Site preparation</u>: Actual costs were $45 per hectare including the late summer plowing to kill grass sod and disking two times.

<u>Planting</u>: Machine planting with a tractor and 3-man crew cost an average 5 cents per tree. The delivered cost of 1-year-old hardwood seedlings was 15 cents per tree.

<u>Weed control</u>: Disking cost $18 per hectare. Casoron powder cost $17.60 per kilogram.

<u>Interest rate</u>: Although a variable, the selected compound interest rate of 5% is used here. The actual rate of interest selected for any project will depend on local economic conditions and public policy.

4. THE MATRIX ANALYSIS

Table I shows the variations of yield by age and plantation density. These data could be tabled as thermal yield, e.g. BTU, joules, etc., according to the manner in which one chooses to express the comparisons. For these purposes, 1 ovendry metric ton contains 18.96 million BTU or 20 billion joules.

TABLE I: YIELD IN DRY METRIC TONS PER HECTARE

	trees per hectare				
Age (n)	7,000	4,700	3,200	2,100	1,400
4	27.5	23.7	20.6	17.4	15.2
5	36.8	32.8	28.9	23.8	21.0
6	43.3	38.2	34.8	31.5	29.3

The next step is to construct Table II, using the average costs by activity from the list of assumptions specified earlier.

TABLE II: ESTABLISHMENT COSTS PER HECTARE					
	trees per hectare				
Activity	7,000	4,700	3,200	2,100	1,400
Site preparation	$ 45.00	$ 45.00	$ 45.00	$ 45.00	$ 45.00
Weed control (2 yrs.)	340.00	340.00	340.00	340.00	340.00
Seedlings @ 15¢	1050.00	705.00	480.00	315.00	210.00
Planting @ 5¢	350.00	235.00	160.00	105.00	70.00
TOTAL	$1785.00	$1325.00	$1025.00	$ 805.00	$ 665.00

To determine growing costs it is necessary to combine the data from Tables I and II and to introduce a carrying charge based upon the selected rate of compound interest. Where i = interest (5%), n = age or years; calculation of the matrix for Table III is from the formula:

$$\text{Growing costs} = \frac{\text{Table II Cost)} \quad (1+i)^n}{\text{Table I yield at n}} \text{ ; thus}$$

TABLE III: GROWING COSTS PER DRY METRIC TON (at 5% interest)					
	trees per hectare				
Age (n)	7,000	4,700	3,200	2,100	1,400
4	78.90	67.96	60.48	56.23	53.18
5	61.91	51.56	45.27	43.17	40.41
6	55.24	46.48	39.47	34.25	30.42

The most important conclusion from Table III is that the cost per unit of production is less at the lower plantation densities. This relates most directly to the lower cost of seedlings at the lower stocking rates.

Land costs are really part of the growing costs. However, we show them separately in Table IV because of significant impact on costs. In some particular situations land costs might not be included, as a matter of policy, where public lands are involved.

To calculate land costs we must adapt the capitalization formula from one which shows a one-time cost carried over a specific time, to one which considers a <u>recurring</u> annual cost that must be paid each year of the rotation. Our adaptation is taken from Davis(2). Thus, the matrix calculations in Table IV are derived by the formula:

$$\text{Land Cost per Metric Ton} = \frac{\$90\ [(1+i)^n - 1]}{i} \div \text{Table I yield}$$

TABLE IV: LAND COSTS PER DRY METRIC TON (at 5%)					
	trees per hectare				
Age (n)	7,000	4,700	3,200	2,100	1,400
4	14.11	16.37	18.83	22.29	25.52
5	13.51	15.16	17.20	20.90	23.68
6	14.13	16.02	17.59	19.42	20.88

Note that land cost is a fixed cost that is paid regardless of total yield. Therefore the higher gross tonnage produced by the higher stocking rates shows the lower range of land costs per ton produced.

Tables III and IV have shown two sides of the production cost problem. To make reasonable conclusions as to the total cost of producing a ton of wood from the various age and spacing alternatives, Table V has been constructed to merge growing costs (Table III) and land costs (Table IV).

TABLE V: TOTAL STUMPAGE COSTS PER DRY METRIC TON (at 5%)					
	trees per hectare				
Age (n)	7,000	4,700	3,200	2,100	1,400
4	$93.01	$84.33	$79.31	$78.52	$78.70
5	75.42	66.72	62.47	64.07	64.09
6	69.37	62.50	57.06	53.67	51.30

The final consideration that we wish to present is the response of stumpage production costs where more than one cutting cycle is planned from the stand by means of coppice reproduction. Two scenarios are shown, both of which make the following important assumptions:

1. Each cutting cycle will be repeated after the same number of years as the original harvest; if the first harvest is made at age 4, succeeding harvests will be made on 4-year intervals, etc.
2. The yield from each harvest within an established repetitive cycle will be the same as the yield from the first harvest in that cycle.

Tables VI and VII have been developed to show the additional efficiency of the investment as a result of extending the plantation to a second cut (Table VI) and a third cut (Table VII). All the previous production costs are applicable, plus we include an additional cost of $120 per hectare for chemical weed control to be applied before the start of each coppice production cycle. Thus the formula for the matrix in Table VI is:

$$\text{Cost per MT} = \frac{\text{Table II cost } (1+i)^{2n} + \$120\,(1+i)^{n} + \text{Rent}\,\dfrac{[(1+i)^{2n} - 1]}{i}}{\text{Table I yield } (1+i)^{n} + \text{Table I yield}}$$

Note that the yield in tons at age n is compounded to the end of the rotation in this case because the market price at the time of harvest is not known. We have determined that market price must equal production cost. If the products from intermediate harvests were actually sold, the money received would be credited to the production account and begin to earn compounded returns. Where market price is unknown, compounding the market volume forward to the end of the rotation has the same effect as compounding the money that the product represents.

TABLE VI: TOTAL STUMPAGE COSTS PER DRY METRIC TON, 2 CUTTING CYCLES

	trees per hectare				
Age	7,000	4,700	3,200	2,100	1,400
4+4	$59.78	$56.43	$55.21	$56.30	$59.02
5+5	50.05	46.12	44.92	47.92	49.55
6+6	47.36	44.44	42.17	42.23	43.10

Computation of Table VII follows the same logic as Table VI with the exception that ther are three yields to calculate at n years and there are two occasions to apply the chemical weed control of $120 per hectare; thus:

$$\text{Cost} = \frac{\text{Table II costs } (1+i)^{3n} + \$120(1+i)^{2n} + \$120(1+i)^{n} + \text{Rent}\,\dfrac{[(1+i)^{3n}-1]}{i}}{\text{Table I yield } (1+i)^{2n} + \text{Table I yield } (1+i)^{n} + \text{Table I yield}}$$

TABLE VII: TOTAL STUMPAGE COSTS PER DRY METRIC TON, 3 CUTTING CYCLES

	trees per hectare				
Age	7,000	4,700	3,200	2,100	1,400
4+4+4	$48.85	$47.24	$47.23	$49.82	$52.55
5+5+5	41.76	39.39	39.18	42.65	44.79
6+6+6	40.22	38.59	37.34	37.19	37.05 1/

1/ This "best case" represents a stumpage production cost of $1.85 per billion joules. Based upon a previous study by Naughton, et al (3) harvesting, chipping, and transportation costs of $1.52 per billion joules ($30.35 per dry metric ton) should be added, for a total estimated delivery cost of $3.37 per billion joules. This compares to a local 1982 market price of $3.88 for natural gas and $4.20 for fuel oil.

5. CONCLUSIONS

The cost of producing wood fuels in plantations is effectively reduced when two or more harvests can be made from one plantation investment. This suggests that the most important silvicultural decision is to select species which coppice vigorously.

Our least-cost solution is found in the plantation with the lowest stocking rate. However, changes in the various input costs listed earlier as assumptions for this analysis can have a profound effect upon the least-cost solution of a particular case. Because the higher stocking rates produce greater total tons per hectare we would choose them in cases where their production costs are equal to or less than the costs from the lower density systems. For comparative purposes, the 7,000 tree per hectare plantations on an 18 year rotation shown on the bottom line of Table VII would have the same production costs per ton as the 1,400 tree option on that same line if any one of the following changes occurred in the assumptions:

1. An increase in the annual cost of land rent to $125 per hectare.
2. A decrease in the cost of seedlings to 11 cents per tree.
3. A decrease in the rate of compound interest to 0.6%.

Significant future opportunities to decrease the cost of production might be found in more efficient weed control methods, use of genetically improved planting stock, the planting of seed instead of seedlings, and/or the judicious use of irrigation and fertilizers. In some situations the concept of least-cost might be appropriately replaced by acceptable-cost systems where the price or unavailability of fossil fuels raises the acceptable limits of what we are willing to invest in wood fuel production. In our situation in Kansas, all of the matrix solutions in Table VII are acceptable when compared to the May 1982 price of fuel oil.

Even if the production tonnages shown in Table I were doubled while input costs remained the same in each example shown here, the least-cost system would still be the plantation with 1,400 trees per hectare. From the standpoint of cost per unit of product, plantation systems designed to obtain maximum biological yield should be carefully evaluated using this matrix system.

This analysis was specifically designed to show the effects of subtle changes in time, yield, rent, and interest rate. Rapid calculation and solution can be made by small programmable calculators and the effects of change in one or more variables can be determined quickly if the basic yield data are known. The Tables presented here have been abbreviated for the sake of example only, and should be expanded to cover additional time and stocking options to the full extent of the data available to the investigator.

6. REFERENCES

(1) Bowersox, T. W. and W. K. Murphey. 1975. "Tree Weight Estimates for Small-sized Trees," Tappi, Vol. 58: 130-131.

(2) Davis, Kenneth P. 1966. "Forest Management." Textbook published by McGraw-Hill, page 337.

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